Ministry of Earth Sciences

The 4th WCSSP India Annual Science Workshop

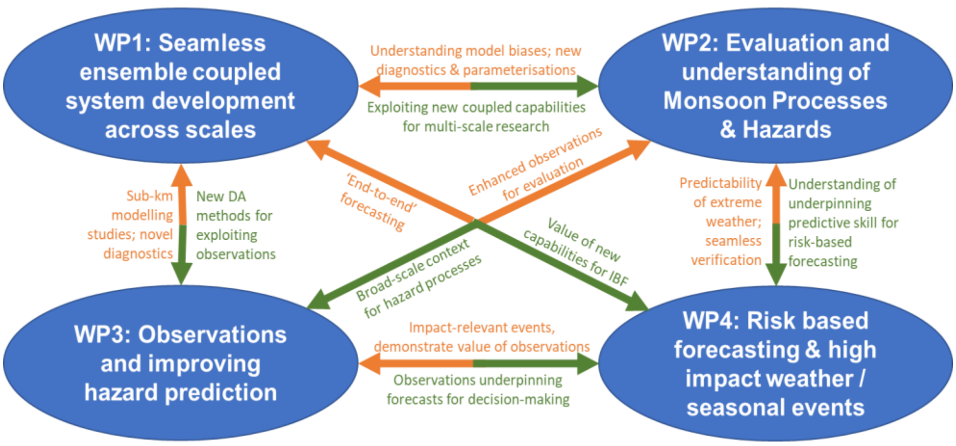
'Pathways to Impact: Building a legacy in Science to Services'

The 4th WCSSP India Annual Science Workshop, hosted by the Ministry of Earth Sciences (MoES), provides a forum to **share**, **discuss** and **evaluate** the advances that have been achieved through collaborative activities in the past year, leading to *more accurate forecasts and earlier warnings of high impact weather* and *enhancing the capacity to transition towards delivery of impact-based forecasting*.

This event provides the first opportunity for face-to-face interactions following 2 years of online-based workshops and meetings. Workshop sessions will be held at MoES in New Delhi (*Monday 27 February 2023*) and at the National Centre for Medium Range Weather Forecasting (NCMRWF) in Noida (*Tuesday 28 February – Thursday 2 March 2023*). Most sessions will also be accessible online.

Objectives:

- Enhance peer-to-peer interactions, networking and developing new research collaborations across the scope of WCSSP India
- Share insights from research progressed under the WCSSP India project across India and UK project partners to support knowledge exchange and identifying opportunities for further strengthening collaboration,
- Discuss impacts and implications of new India-UK research and the resulting opportunities for translating into improved services via MoES partners,
- Develop deepening peer-to-peer and cross-institute research networks to address key outstanding challenges for improving observations, modelling and research capability on natural hazard prediction in the Indian monsoon system, leading to enhanced risk-based services.



PLENARY 1 Monday 27th February 2023

Impact of the urbanization and aerosol in predicting extreme weather events using sub-km model

A.Jayakumar, (NCMRWF) Anthony Jones, Anurose T.J, Hamish Gordon, Saji Mohandas

Upgraded version of DM-Chem with RAL3 for the winter 2022-2023 was introduced with an additional feature of UKCA coupled to cloud-aerosol interactive double moment microphysics scheme, CASIM, and local urban canopy parameterisation schemes, MORUSES. Even after incorporating aforementioned changes, over estimation of the visibility and the under-estimation of surface PM concentration is prevailed during the deep foggy case from the current offline oxidants chemistry configuration. Hence the DM-Chem with the complex chemical composition (stratosphere-troposphere chemistry) will be tested and assessed against the default offline configurations for those case events. Moisture and the radiative heating balance from the two UKCA science configurations within DM-Chem model will be presented in the workshop.

Indian summer monsoon precipitation biases in GloSea and CFS and their response to large-scale drivers

Richard Keane (Met Office) Ankur Srivastava, Gill Martin

Previous work has shown that Met Office weather forecasts during the Indian summer monsoon (ISM) initially have too much precipitation over India, but that this decreases throughout a 7-day forecast so that there is too little precipitation by the end. The precipitation decrease has been shown to vary with the observed phase of the Boreal Summer Intra-Seasonal Oscillation (BSISO), with a smaller reduction during active to break transitions and generally a smaller reduction for active phases than for break phases. We have also shown that the major systematic errors in the ISM in Met Office models are established within the first few days of simulation and can then persist to climate timescales. The current work extends this analysis to seasonal hindcasts from the Met Office (GloSea5-GC2, GloSea6-GC3.2) and IITM (CFSv2) coupled forecasting systems.

A negative bias appears in GloSea within 10 days, and persists at a fairly constant value thereafter, it is substantially reduced in GloSea6. In CFS there is a similar initial decrease, followed by a recovery to ~50 days and then a decrease back to the same bias as in GloSea5. To investigate this further we split the forecast coherent (lead-time) periods and show that there are some similarities in the development of wind and precipitation fields between GloSea and CFS. The influence of sea surface temperature is also evaluated.

The hindcasts are divided by observed BSISO phase and it is found that the precipitation biases are worse in all systems during break to active transitions, particularly in GloSea5. The systems show similar initial dependence on phase, with the largest precipitation reduction for phases 3 and 4 during the first 8 days and for phases 4 and 5 during the next 8 days. Thereafter, the dependence on observed phase reduces, disappearing at roughly 50 days lead time.

PLENARY 2 Monday 27th February 2023

Lightning prediction over India on seasonal timescales

Anupam Hazra (IITM), Chandrima Mallick, Greeshma M. Mohan, and Ushnanshu Dutta

Skillful seasonal prediction of lightning is crucial over several global hotspot regions, as it causes severe damages to infrastructures and losses of human life. While major emphasis has been given for predicting rainfall, prediction of lightning in one season advance remained uncommon, owing to the nature of problem, which is short-lived local phenomenon. Here we show that on seasonal time scale, lightning over the major global hot-spot regions is strongly tied with slowly varying global predictors (e.g., El Niño and Southern Oscillation). Moreover, the sub-seasonal variance of lightning is highly correlated with global predictors, suggesting a seminal role played by the global climate mode in shaping the local land-atmosphere interactions, which eventually affects seasonal lightning variability.

It is shown that seasonal predictability of lightning over the hotspot is comparable to that of seasonal rainfall, opens up an avenue for reliable seasonal forecasting of lightning for special awareness and preventive measures.

Wider application and evaluation of the Flood Hazard Impact Model for India (FHIM-India)
Steven Cole (UKCEH), Raghavendra Ashrit (NCMRWF), Seshagirirao Kolusu (Met Office)

In common with many countries across the world, India are developing Impact-based Forecasting (IbF) and warning approaches aligned to the World Meteorological Organisation (WMO) guidelines. Flooding is a major issue for India, with climate change and growing populations only increasing the potential risks. In response, the WCSSP India programme has been developing the Flood Hazard Impact Model for India (FHIM-India) aimed at real-time and automated IbF.

The FHIM-India development has been using the Hazard Impact Framework (HIF) created by the UK's Natural Hazards Partnership (NHP). Currently FHIM-India is in the "prototype" HIF phase, creating automated end-to-end FHIM-India workflows that use NEPS-R ensemble forecasts, the Grid-to-Grid (G2G) distributed hydrological model, the HiPIMS (High-Performance Integrated hydrodynamic Modelling System) at ~30m resolution, and Impact Library and Risk calculation methods. These have been developed and deployed on the UK's JASMIN computing infrastructure using the Cylc workflow manager used by NCMRWF and Met Office for the Unified Model.

Recent activity has focussed on sharing the FHIM-India workflows and training Indian and Met Office colleagues in applying and evaluating them, together with extending the application to other regions of Kerala and iterative improvements in the workflow components and flexibility informed by user feedback. Examples of recent developments will be provided, including research led by the Met Office on analysing the sensitivity of different NWP ensemble rainfall forecast inputs (MOGREPS-G (Met Office) and NEPS-R (NCMRWF)) for FHIM-India flood impact and risk assessments. Providing UK and Indian colleagues with hands-on training and experience of applying the FHIM-India workflows is allowing partners across WCSSP-India to include FHIM-India in future plans towards operational trials and implementation for flood IbF.

PLENARY 3 Monday 27th February 2023

Role of atmospheric heat fluxes and ocean advection on decadal (2000–2019) change of sea-ice in the Arctic Arnab Mukherjee, (NCPOR), M. Ravichandran

In this article, role of ocean advection and atmospheric heat fluxes on recent decadal (2000–2019) decrease of sea-ice in the Arctic (60 N–90N) has been investigated using an ocean sea-ice coupled model, known as Modular Ocean Model of version 5 with Sea Ice Simulator (MOMSIS). MOMSIS successfully simulates AVHRR observed decadal change of sea-ice concentration (SIC) and sea surface temperature (SST) in the Arctic during all four seasons; winter (December–February), spring (March–May), summer (June–August) and autumn (September–November) except few occasions. Also, best performance of the MOMSIS are restricted at south of 80 N with statistical significance of more than 90 %.

We have also divided Arctic Ocean into eight sectors for our detailed analysis. Maximum decadal decrease of SIC and increase of SST has been observed in the Barents (sector 2), Kara (sector 3) and Laptev (sector 4) Sea regions of the Arctic using both AVHRR and MOMSIS with statistical significance of 90 %. Also, very small decadal decrease (increase) of SIC (SST) has been observed in the Norwegian (sector 1) and Beaufort (sector 7) Sea regions of the Arctic using both AVHRR and MOMSIS. Mixed layer heat budget has been performed to understand role of thermodynamics processes on decadal change of SIC and SST in the Arctic. Strong decadal change of net atmospheric heat (NAH) fluxes are responsible for high decadal change of SIC and SST in the Barents (sector 2), Kara (sector 3) and Laptev (sector 4) Sea regions of the Arctic. In the Norwegian (sector 1) and Beaufort (sector 7) Sea, strong destructive interference between decadal change of NAH fluxes and ocean advection play an important role for small decadal change of SIC and SST during all four seasons. Also, for ocean advection, horizontal part dominate compared to vertical in all eight sector of the Arctic.

On the utility of ensemble rainfall forecasts over river basins in India

Anumeha Dube (NCMRWF), Raghavendra Ashrit

Rivers are very important for the agriculture based economy in India, but recent heavy rainfall events have caused major floods in the rivers resulting in loss of life and property. In order to accurately forecast the stream flow from the rivers firstly, an accurate forecast of rainfall over the river basins (RB) is required. Until recently, for operational flood forecasting in India, rainfall forecasts from deterministic models were used. This study seeks to address the question 'whether the ensemble rainfall forecasts over RBs in India are ready for hydrological applications?' For this purpose, we have carried out an in-depth verification of the probabilistic rainfall forecasts obtained from the NEPS over 5 major RBs of India during the southwest monsoon (SWM) seasons of 2018 to 2021. The basin averaged rainfall forecasts from NEPS and observations from IMERG are used in this study.
This study shows that the model possesses good skill in predicting low to moderate rainfall over Ganga and peninsular rivers like Tapi, Narmada, Cauvery, and Krishna. This is seen in terms of a low Brier Score (BS), high Brier Skill Score (BSS) and low Continuous Ranked Probability Score (CRPS). The skill of the model is further confirmed by comparing the RMSE in the mean with the spread in the members. The best match between the RMSE in ensemble mean and spread is seen for Ganga RB. It is seen that over Ganga, Mahanadi, and Narmada the rainfall forecasts show the maximum economic value. However, the model shows relatively poorer skill in predicting rainfall over the Brahmaputra RB located in northeastern India. From this study it can be concluded that NEPS model has reasonably good skill in predicting rainfall over RBs in northern and peninsular parts of India and it would be beneficial to use these forecasts for forecasting floods.

Extreme weather events of 2022, their impacts and impact-based forecasting

RK Jenamani, IMD

PARALLEL SESSION 1: Impact modelling and forecasting techniques
Tuesday 28th February 2023

Extreme Weather Events induced mortalities in Jammu and Kashmir, India during 2010- 2022	**Mukhtar Ahmed**	**IMD**
Assessment of Heavy rainfall and Impact Based weather forecast over Arunachal Pradesh during the southwest monsoon	**A. Sandeep**	**IMD**
Heavy rainfall warning and Impact based forecasting for the subdivision of Tamilnadu, Puducherry & Karaikal during the northeast monsoon season	**B. Geetha**	**IMD [online]**

For the meteorological subdivision of Tamilnadu, Puducherry & Karaikal (TN) the northeast monsoon season of October to December is the chief rainy season and the state's agricultural and hydrological activities depend on rainfall during this season. Synoptic systems such as westward moving trough in easterlies / easterly waves and low pressure areas over Bay of Bengal cause extreme rainfall events over this subdivision. Further, this season is also the chief cyclone season for the North Indian Ocean and the tropical depressions and cyclones forming over the Bay of Bengal and crossing the extreme southeastern coast of peninsular India often cause extreme rainfall events leading to coastal inundation, inland flooding, damages to crops and livestock as well as loss of lives and property.

Designing an Impact-based Forecasting evaluation methodology using hazard and impact observations	**Elizabeth Dyson**	**Met Office**

The Vehicle Overturning (VOT) Model (Hemingway and Robbins, 2020) is a prototype Hazard Impact Model (HIM) designed to forecast the risk of major roads being blocked by overturned vehicles in windy conditions. An ensemble-based version of the model has been running continuously (on a non-operational basis) since late 2013, with outputs available to operational meteorologists to assist with the issuance of impact-based warnings.
Evaluating the performance of HIMs has remained challenging. This has previously been due to a lack of impact observations. Recent work to routinely collect impact information related to the transport sector has enabled the first investigations into a robust and routine approach to HIM forecast evaluation. Current work is focused on developing a robust evaluation methodology to quantitatively assess the performance of the VOT model and to undertake routine skill assessments.
To achieve this the availability, accessibility and post-processing requirements of both hazard and impact observation datasets are being assessed and compiled. Following this a workflow will be developed to compare hazard and impact observations with VOT modelled risk.
This presentation will describe current progress, highlighting methods and tools used, challenges encountered and early results.

Developing Impact-Based Forecasting of heavy rainfall and agriculture for the state of Jharkhand	**Abhishek Anand**	**IMD [online]**

Any weather events such as heavy rainfall, drought and flooding, severe storms, heat waves, and cold waves that are unusual for a particular place and severe in their effects are termed as extreme weather events. The observed intensity, frequency, and spatio-temporal extent of extreme events have been changing with the changing climate system. These extreme weather events negatively affect our ecosystem and economic activity, so just providing the conventional weather forecast is not sufficient. It is also crucial to integrate weather forecasts with information about the severity of weather events and their likely impacts. Thus, in this context, India Meteorological Department started providing Impact Based Forecast (IBF) following the WMO guidelines. In this work, we describe the Impact Based Forecast prepared by the Meteorological Centre Ranchi for 24 districts of Jharkhand. A risk-impact matrix for each district has been prepared in order to issue district-specific Impact Based Forecasts for Heavy Rain. Various attributes, viz., topography, LULC (Land Use Land Classification), rivers, dams and reservoirs, soils etc., for each district, has been considered in quantifying the threshold of hazardous events. Heavy Rainfall frequency of past 12 years (period: 2011-2022) has been analyzed, and the eastern region of Jharkhand has been found to be more prone to Heavy Rainfall events. In IBF Bulletins, GIS based Maps are included, and the concerned district/sector with forecasted impact are highlighted/color-coded to issue unambiguous warning alerts to the public. Emphasis is given to the agriculture sector, for which the IBF integrated with crop advisory is issued. To improve the accuracy of IBFs issued, monthly verification of IBFs using realized heavy rainfall events data are carried out. Data regarding impact on the farm sector has been collected using the network of KVKs (Krishi Vigyan Kendra) and DAMUs (District Agro-Met Units) under the GKMS (Gramin Krishi Mausam Sewa) scheme.

Investigating the unprecedented heavy rainfall activity over Northeast India and their impact during 13-15 May 2022	**Himadri Vaiasa**	**IMD**

Impact based Forecast and Risk based Warning System for Heavy Rainfall in India: A Review	**Shobhit Katiyar**	**IMD**

Many areas of India are prone to several natural hazards. Over its nearly 148 year of history, IMD has steadily improved its observational networks and predictions and warning services to protect the public from severe weather. Each year severe meteorological events give rise to multiple casualties and significant damage to property and infrastructure. Many of these events have been well predicted and disseminated in a timely manner in recent years. However there is still gap between weather forecast and its impact and this gap can be closed by development in observing network, modeling, prediction and hazard & impact modeling. Here various components of IBF and RBW system for heavy rainfall and its implementation in IMD are discussed alongside the various challenges.

Study of rainfall thresholds for Impact based forecast for monsoonal rainfall over Gujarat using percentile analysis	**ViginLal F**	**IMD**

Steps towards a probabilistic seamless blended multi-model weather pattern forecasting tool for India	**Robert Neal**	**Met Office [online]**

Preliminary research undertaken to develop a seamless blended multi-model version of the existing probabilistic medium-range weather pattern forecasting tool for India is described. In this research, “seamless” refers to a single forecast which can be used out to any lead time. “Blended” refers to different models being blended in and out as the forecast lead time progresses. Finally, “multi-model” refers to taking an average of forecast probabilities from several models. The existing (individual model) forecasting tool was developed over recent years under the WCSSP-India project and is currently running in real time at IMD using output from the IMD-GEFS and NCMRWF global ensembles. There is also a third version running at the Met Office using output from the ECMWF global ensemble. Real time output from all three versions can be viewed at https://gws-access.jasmin.ac.uk/public/wcssp_india/weather-patterns/. Objective verification of Indian weather pattern forecasts from individual models shows forecast skill out to 10 days for most weather pattern groups, with this latest research investigating if skill can be improved using a muti-model approach. Such an approach has already been shown to add skill over Europe, with the added benefit of only having one forecast to look at hence easing the decision-making process for operational meteorologists. Multi-model results will be presented for Europe, along with a proposed seamless blended multi-model configuration for India suitable for implementing in real time in the near future.

PLENARY SESSION 7: Impact modelling and forecasting techniques

Wednesday 1st March 2023

Impact-Based Forecasting and Warning: Methodology, and Implementation for North East India	Arun Kumar VH, IMD

Meteorological services are changing their usual way of providing simple weather warnings toward risk-based warnings, termed "Impact-based Forecasting" by WMO, which integrates the likelihood and severity of impacts due to severe weather (WMO, 2015; Silvestro et. al., 2019). Impact Based Forecasting (IBF) helps the public and the communities to prepare appropriately for the threats expected from severe weather events (WMO, 2015). IBF can lead to an improved understanding of forecasts (Potter et. al., 2018) and may increase peoples' intention to take protective measures against severe weather (Casteel, 2016; Weyrich et. al., 2018). This present study deals with a methodology for the impact-based forecast (IBF) for the state of Assam, in connection with heavy rainfall events. The past experiences of various impacts of heavy rainfall events and their severity were studied and documented for Assam to implement IBF in the operational mode. Based on the topographical as well as physiographical data, the districts of Assam were segregated into Hilly as well as Plain districts. An impact matrix was prepared for these clusters of districts and presented in the current study as a part of the risk assessment. From the historical data, the days of impact were identified, and rainfall that led to the impacts is also collected. The hazard thresholds which created various impacts like landslides, and flooding were estimated for these clusters of districts, and an impact matrix corresponding to various impact levels is formulated. All the collected impact events are tabulated in the impact matrix under various levels, namely, minimal, minor, significant, and severe. Heavy rainfall in a single day may not create so much impact and may depend upon the previous day's rainfall too. To account for this factor, five-day cumulative rainfall up to the day of the event is calculated, the cumulative rainfall is categorized into different ranges, and the level of impacts is segregated under the respective rainfall ranges. In this way, a lookup table for the impact category against the hazard threshold is generated, which is being utilized for issuing IBF over different clusters of districts. The same methodology is adapted for the preparation of the impact matrix for the rest of the states in North East India. Regional Meteorological Centre, India Meteorological Department, Guwahati is operationally issuing IBF for all the States in Northeast India as well as for Guwahati city since 2020. It is planned to fine-tune the impact matrix by collecting more historical impact data, exposure data, vulnerability data, etc.

Satellite derived impacts of flooding in Bihar, India	Barbara Hofmann, HR Wallingford

India, and Bihar in particular, regularly experience severe flooding. Measurements of flood impact are needed both to act as verification data for the development and testing of impact-based forecast models and to enable efficient targeting of relief resources
We present research into using earth observation data to estimate the impact of flooding on agriculture and the built environment in Bihar, India in 2020. Heavy rainfall hit northern Bihar in July 2020 causing wide-spread flooding. Villages were flooded or cut-off and hundreds of acres of Kharif crops were destroyed.
We generated flood extent and duration from synthetic aperture radar (SAR) data over a five month period following the flood onset, and combined these with Normalised Difference Vegetation Index (NDVI) data, derived from multispectral satellite data, OpenStreetMap data (OSM) and population data sets to derive impact.
For disaster management the short-term impact on the built-environment is particularly useful. We identified roads blocked by flooding and developed an index which enables us to estimate the

impact on settlements in terms of access to key facilities such as hospitals, and update this as time progresses. The impact on agriculture is long-lasting with flood water remaining for up to four months in areas, encroaching on the sowing period of the following Rabi season. Our results are presented on our prototype website which allows us to interrogate areas in detail.	
Impact based forecasting of heavy rainfall over Maharashtra	Nitha.T.S, IMD

PARALLEL SESSION 2: Understanding model error evolution, physical processes and scale interactions

Tuesday 28th February 2023

Examining the behaviour of monsoon low-pressure systems under contrasting soil moisture conditions in India	**Akshay Deoras**	**University of Reading**

Indian monsoon low-pressure systems (LPSs) are synoptic-scale cyclonic vortices that produce abundant precipitation over the Indian subcontinent. Despite their capability to cause catastrophic flooding, the role of land-surface conditions in their propagation remains less explored. In this work, we use the volumetric soil moisture data (0–7 cm layer) from the ERA5 reanalysis dataset to analyse the role of soil moisture in LPS propagation. We use a catalogue of LPSs, which were identified in ERA5 using a feature-tracking algorithm. We consider only those LPSs that had their genesis over the Bay of Bengal (BoB) during June–September 1979–2021 and lysis over India or neighbouring countries.

We find that for a composite of LPSs having their lysis over eastern India (i.e., short-lived LPSs), the soil ahead and in advance of them is consistently dry compared to the climatology, differing from the presence of wet soil ahead of long-lived LPSs. There are dry soil moisture anomalies over southeastern India and Sri Lanka for a composite of long-lived LPSs. This indicates the effects of suppressed antecedent precipitation over these regions, which could be reflecting BSISO phases 4–5 when LPSs are most frequent over the BoB and eastern India. Whilst dry land surface conditions over central India could be forcing an early lysis of LPSs, the large-scale circulation associated with the BSISO could be exerting control on the LPS propagation. Thus, the results of this work could motivate researchers to conduct sensitivity tests using the WRF model to determine which factor is dominant.

Nonlinear intensification of monsoon low pressure systems by the BSISO	**Kieran M R Hunt**	**University of Reading**

More than half of the rainfall brought to the Indian subcontinent by the summer monsoon is associated with low-pressure systems (LPSs). Yet their relationship with the Boreal Summer Intraseasonal Oscillation (BSISO) – the dominant intraseasonal forcing on the monsoon – is only superficially understood. Using reanalysis data, we explore the relationship between the BSISO and LPS intensity, propagation, and precipitation, and associated underlying mechanisms.

The BSISO has a large impact on mean monsoon vorticity and rainfall as it moves northward – maximising both in phases 2-3 over southern India and phases 5-6 over northern India – but a much weaker relationship with total column water vapour.

We present evidence that LPS genesis also preferentially follows these phases of the BSISO.

We identify significant relationships between BSISO phase and LPS precipitation and propagation: for example, during BSISO phase 5, LPSs over north India produce 51% heavier rainfall and propagate northwestward 20% more quickly.

Using a combination of moisture flux linearisation and quasigeostrophic theory, we show that these relationships are driven by changes to the underlying dynamics, rather than the moisture content or thermodynamic structure, of the monsoon.

Using the example of LPSs over northern India during BSISO phase 5, we show that the vertical structure of anomalous vorticity can be split into contributions from the BSISO background circulation and the nonlinear response of the LPS to anomalous BSISO circulation. Complementary hypotheses emerge about the source of this nonlinear vorticity response: nonlinear frictional convergence and secondary barotropic growth. We show that both are important. The BSISO imparts greater meridional shear on the background state, supporting LPS intensification. The BSISO background and nonlinear LPS response both contribute significantly to anomalous boundary layer convergence, and we show through vortex budget arguments that the former

supports additional LPS intensification in boundary layer while the latter supports faster westward propagation.
This work therefore yields important insights into the scale interactions controlling one of the dominant synoptic systems contributing to rainfall during the monsoon.

The diagnosis of the extended range ERPAS and GloSea5 models under the influence of the extratropical-tropical interactions	**Mahesh Kalshetti**	**IITM**

The atmospheric general circulation during extratropical-tropical interactions is characterized by anomalous mean-flow modulation brought on by transient eddy transport and related eddy forcing. The transient eddy momentum and heat flux transport from extratropical to tropical regions cause significant weather and climate variations. The present analysis systematically quantifies the hindcast skill of the Indian Institute of Tropical Meteorology ERPAS and Met Office GloSea5 extended-range models during the Indian summer monsoon when the extratropical transient intrusions into the tropics are prominent. In particular, over the entire Western Ghats and north-west India during extratropical eddy intrusions, the composites of the days of poleward heat flux transport and equatorward momentum flux transport on a daily scale and the composites of days of equatorward heat flux transport and poleward momentum flux transport on a quasi-biweekly scale suggest an increase in current rain activity. During the Indian summer monsoon days, especially over the north Indian region, ~60% of rainfall events show no influence of extratropical intrusions, while ~40% of rainfall events are associated with the transient eddy feedbacks oscillation phases (tropical mode), and the zonal transport of wave number 7-8 pattern (extratropical mode). At 1-week lead periods, both the ERPAS and GloSea5 models are capable of forecasting the rainfall in northern India under the influence of extratropical EMF and EHF, but beyond that, their accuracy declines.

Seasonal uncertainty assessments of NCMRWF global ensemble prediction system	**Paromita Chakraborty**	**NCMRWF**

An ensemble forecast provides an estimate of the forecast probability distribution of model variables, given an estimate of the probability distribution of analysis errors. The combined effect of uncertainties in model physics and the initial state provides a means to increase the dispersion of ensemble prediction systems. The ensemble prediction system based on Met Office Global and Regional Prediction Systems (MOGREPS) at NCMRWF is assessed in this study. The model physics is perturbed by the Stochastic Kinetic Energy Backscatter (SKEB) and Random Parameters (RP) schemes. The RP scheme incorporates uncertainties in the empirical parameters of the physical parameterization. The SKEB scheme is implemented in the Unified Model to inject the loss in kinetic energy back into the model. The global perturbation fields for wind, temperature, humidity and pressure are produced by the Ensemble Transform Kalman Filter method. The representativeness of an EPS is analyzed from the distribution of initial and forecast ensemble dispersion. The vertical profiles, latitudinal and longitudinal variations of dispersion of the ensemble are evaluated in this study for geopotential height at 500 hPa, temperature and relative humidity at 850 hPa to obtain physical insights into the uncertainty characteristics of the EPS over different seasons so that we can identify ways to improve the ensemble configuration.

Intraseasonal Oscillation of Land Surface Moisture and its link with the active phases of the Indian Summer Monsoon	**Pratibha Gautam**	**IITM**

What is the role of soil moisture in maintaining the land ITCZ during the active phase of the monsoon? This question has been addressed in this study first by using ERA5 reanalysis datasets, and then we evaluate the question in the CFS model-free run. Like rainfall, land surface parameters (soil moisture and evaporation) also show intraseasonal oscillation. Furthermore, the sub-seasonal and seasonal features of soil moisture are different from each other. During the summer monsoon season, the maximum soil moisture is found over western coastal regions, central parts of India, and the northeastern Indian subcontinent. However, during active phases of the monsoon (i.e., on sub-seasonal timescales), the maximum positive soil moisture anomaly was found in North West parts of India. Land surface characteristics (soil moisture) also play a pre-conditioning role during active phases of the monsoon over the monsoon core zone of India. When it is further divided into two boxes, the north monsoon core zone, and the south monsoon core zone, it is found that the preconditioning depends on that region's soil type and climate classification. Also, we calculate the moist static energy (MSE) budget during the monsoon phases to show how soil moisture feedback affects the boundary layer MSE and rainfall. A similar analysis is applied to the model run, but it cannot show the realistic preconditioning role of soil moisture and its feedback on the rainfall as in observations. We conclude that to get proper feedback between soil moisture and precipitation during the active phase of the monsoon in the model, the pre-conditioning of soil moisture should be realistic.

Process-oriented diagnostics in NCUM global forecasts during monsoon season	**Mohana S Thota**	**NCMRWF**

This study aims to assess the capability of the National Center for Medium-Range Weather Forecasting Unified model's (NCUM) global (12km) version in representing the process-based diagnostics during the contrasting monsoon rainfall phases over Indian region. Column integrated moisture budget analysis is performed on the model's forecast fields for a typical break and active monsoon episodes during 2015-2021. Results are validated by repeating the budget exercise using the NCUM analysis and European Center for Medium Range Weather Forecasting Reanalysis (ERA5) data products. Despite having the model biases in the mean state of rainfall and winds over Indian subcontinent, the results obtained by performing the process-based diagnostics are consistent with our understanding that the moisture advection acts as a leading term in inducting the active/break conditions over Central Indian (CI) region. One of the direct implications of this work is that the lead times obtained in the moisture budget assessment can be used to understand and improve the model forecasts.

Cohesive influence of Greenland Sea ice, Eurasian snow and ENSO on the diverse nature of South and East Asian Monsoons	**Amita Prabhu**	**IITM**

Mutual impacts of Greenland Sea ice, Eurasian Snow, and ENSO (El Niño–Southern Oscillation) on out-of-phase relationship between Indian Summer Monsoon (ISM) and Korean Summer Monsoon (KSM) have been investigated through observational and numerical experiments. Results reveal that non-linear responses of Indian and Korean summer rainfall to ENSO and Greenland Sea ice forcing prevail when both the events co-occur. Above normal Greenland Sea ice along with a con-current La Niña showed a distinct in-phase relationship with ISM while having an out-of-phase relationship with KSM. Further, below (above) normal Greenland sea ice during boreal autumn causes anomalous low (high) pressure surrounding Greenland, which may be associated with barotropic +west/−east or –west/+east dipole pattern, respectively, over Eurasia during subsequent winter and spring seasons. Additionally, this pattern leads to positive (negative) snow depth anomaly over western Eurasia while having an opposite snow tendency over eastern Eurasia in subsequent spring. Further, this variability in Eurasian snow pattern may play a crucial role on the contrasting pattern of ISM and KSM. Furthermore, co-occurrence of ENSO variability also generates high- and low-pressure anomaly patterns over the Indian Ocean that may be related to unfavourable or favourable ISM, respectively, while influencing negative or positive phases of a Pacific Japan (PJ)-like teleconnection pattern that may be related to unfavourable or favourable KSM, respectively. Therefore, coexisting ENSO forcing may play a dominant role in ISM and KSM, but Greenland Sea ice forcing and Eurasian snow variation intensify an out-of-phase relationship between the south and East Asian monsoons.

Global wave model coupling to GC5 climate model	**Nikesh Narayan**	**Met Office [online]**

Recently the environmental forecasting methodology is gravitating towards using integrated modelling systems, where almost all the processes controlling transfer of energy and matter between the system components are represented. Recent studies suggest that due to the improved accuracy in calculation of wind stress in the atmosphere and vertical mixing in the ocean, a fully coupled Ocean-Wave-Atmosphere (OWA) modelling system was found to be more effective in forecasting extreme weather events like tropical cyclones. Closely following the development of the latest Met Office global Ocean-Atmosphere coupled model (GC5), we have introduced a fully coupled global wave model (based on WAVEWATCH III) to GC5. The wave model derived Charnock parameter coupled to the atmosphere model introduced sea-state dependence in the calculation of surface wind stress. In the ocean, the Stokes drift velocity coupled from wave to ocean enters the wave-averaged momentum equation and tracer advection equation. It also enables to represent the Stokes-Coriolis effect which causes changes in the Ekman turning of ocean surface current influencing the vertical mixing in the ocean. Additionally, the stress difference caused by growing and breaking of waves is also ‘felt’ by the ocean due to the coupling of wave-ocean momentum flux. A 50-year climate run was performed using this OWA model and evaluated against an equivalent GC5 run. The initial assessment suggests that the changes from wave coupling is mostly neutral, with some improvements in Global tropospheric assessment matrices like precipitation in the Northern hemisphere and relative humidity. Changes are also mostly neutral in the Southern Ocean. However, significant changes in sea surface height (SSH) were observed in the south-eastern Pacific and the Agulhas region. We have identified that further improvements are needed in the wave coupling strategy and work is underway to upgrade roughness closure wave atmosphere coupling to momentum closure coupling and to update the turbulent closure vertical mixing scheme in the ocean to incorporate additional wave parameters such as wave induced pressure and Langmuir circulation.

PLENARY 9: Understanding model error evolution, physical processes and scale interactions

Wednesday 1st March 2023

Using relaxation experiments to understand drivers of systematic errors in the Asian Summer Monsoon	Gill Martin, Met Office

Understanding the sources of errors in the modelling of monsoon systems requires the combination of various modelling techniques and sensitivity experiments of varying complexity. Here, we demonstrate how such analysis can shed light on the way in which monsoon errors develop, their local and remote drivers and feedbacks. We show that error patterns in circulation and rainfall over the Asian summer monsoon (ASM) region in Met Office models are similar between multidecadal climate simulations and seasonal hindcasts initialised in spring. Analysis of the development of these errors on both short-range and seasonal timescales following model initialisation, combined with the use of regional relaxation experiments, suggests that both the Maritime Continent and the oceans around the Philippines play a role in the development of East Asian summer monsoon errors, while errors over the Equatorial Indian Ocean (EIO) region are associated with circulation errors over India and the strengthening and extension of the westerly jet across Southeast Asia and the South China Sea into the West Pacific. We also find that the Maritime Continent plays an important role in the development of wind errors that force sea surface temperature (SST) errors around the Indonesian islands and in the eastern Indian Ocean. The EIO itself plays a key role, however, in the further development of an east-west SST dipole error, and we hypothesise that the

atmosphere circulation errors in these two regions combine with an ocean circulation response in a coupled feedback that affects the ASM as a whole.	
Indian Monsoon Subseasonal Variability and Arctic Amplification	Rajib Chattopadhyay, IITM
This study examines the impact of a decrease in sea ice temperature due to Arctic amplification on the summer monsoon circulation over the Indian Region. The results were analyzed based on model simulations in which the latitudinal extent of arctic sea ice is decreased in one experiment and raised in another. The month with the lowest (highest) sea-ice extent is used to drive the GFS model to depict the warming (cooling) scenario resulting from Arctic amplification. The twin experiment is done to see whether the monsoon sensitivity in a warming and cooling scenario is reversed. Surprisingly, the monsoon declines in all circumstances, demonstrating that the monsoon circulation is associated with equator-to-pole heat gradients and is not merely the equatorial to tropical components of general circulation. The analysis also reveals a significant modification in the mid-latitude circulation, which impacts the tropical-extratropical interaction, the transport of heat and momentum fluxes, and the teleconnections. The most notable finding of the investigation is a rise in precipitation across the Himalayas, the foothills of the Himalayas, and the northeastern sections of India. The recent increase in extreme events in these areas may be related to the changes in sea ice concentration.	
Progress towards km-scale coupled global modelling	Huw Lewis, Met Office
K-Scale is a research project to develop very large domain regional and global modelling capability at kilometre grid-scale to improve our understanding and predictions of the influence of upscale processes on weather and climate. This requires strong alignment with related international activities and builds on a heritage of convective-scale model research on national to continental domains across timescales in the Met Office and wider UK academia. This research will provide the evidence required on the scientific and technical costs and benefits of K-Scale models for implementation in next-generation applications on weather and climate timescales. The project is developing and evaluating kilometre grid-scale coupled simulations based on the Unified Model (subsequently LFRic) atmosphere codes on very large regional to global domains (>1bn grid points). In doing so, we will assess the upscale influence of tropical convection on weather and climate in the tropics and extra-tropics and exploit the benefits from K-Scale simulations as a rich data source to support parameterisation development, machine learning applications and other research.	

PARALLEL SESSION 3: Improving prediction of visibility and fog over the Indian subcontinent

Tuesday 28th February 2023

Development and implementation of drop Size distribution parameterization based on CAIPEEX observation data in high resolution GFS-T1534 model	Sahadat Sarkar	IITM

Over Indian region, mixed phase clouds are very important in producing rainfall during monsoon season but no in situ observations of particle size distribution (PSD) were available. CAIPEEX (Cloud Aerosol Interaction and Precipitation Enhancement Experiment) provides the microphysical parameters including PSD over the Indian region. To improve the microphysics parameterization, we have modified drop size distribution (DSD) in high resolution GFS T1534 model based on observation data from CAIPEEX. The particle size in the GFS model with WSM6 (WRF Single Moment 6 class) microphysics is represented by an exponential fit of the form- N(D)= N0e-λD where N0 is the intercept, λ is the slope and D is the diameter of the particle. The choice of N0 remains problematic for the microphysical schemes, whether a constant value or variable (Lin et al. 1983). But most of the microphysical schemes assume N0 as constant and same is true for GFS T1534 model also. Analysis of CAIPEEX data shows that N0 and λ are co-related (Patade et al. 2015; Patade et al. 2016). Also, it varies with temperature which is not consistent with the assumption that N0 is constant. In fact, there appears to be a nearly linear relation between log(λ) and log(N0), i.e. of the form
log(N0) = alpha + beta log(λ) whose slope beta is 2.033 (Using 2011 CAIPEEX data)

So, we can write N0 = C (λ)2.033 where C is constant. The point here is that, instead of assuming that N0 as constant which is not consistent with the CAIPEEX analyses, we can instead replace this assumption with the equation N0 = C (λ)2.033. GFS T1534 model shows the drop size distribution (DSD) modification captures the depression cases during 13 Sep, 2021 better that the default GFS T1534 model simulation. DSD modification shows that the model can capture the events with 5-day lead and the structures are better captured in day-1 and day-3 lead compared to the default GFS T1534 model. The over-estimation of the rainfall over Bay of Bengal region is significantly reduced in the DSD simulation. DSD simulation can capture the along-track rainfall during the depression events better than the GFS-T1534 default model. Along with that the vertical structure of relative humidity, convective and large-scale rainfalls are better captured in DSD modification.

WiFEX: Walk into the warm fog over Indo-Gangetic Plain region	Sandeep Wagh	IITM

The presence of persistent heavy fog in northern India during winter creates hazardous situations for transportation systems and disrupts the lives of about 400 million people. The meteorological factors responsible for its genesis and predictability are not yet completely understood in this region. Given its high potential for socio-economic impact, there is a pressing need for extensive research that understands the inherently complex nature of the phenomena through field observations and modeling exercises. WiFEX is a first-of-its-kind multi-institutional initiative dealing with intensive ground-based measurement campaigns for developing a suitable fog forecasting capability under the aegis of the smart cities mission of India. Measuring campaigns were conducted between the 2015–2020 winters at the Indira Gandhi International Airport, New Delhi, covering more than 90 dense fog events. The field experiments involved extensive suites of in-situ instruments and gathered simultaneous observations of micro-meteorological conditions, radiative fluxes, turbulence, droplet/aerosols microphysics, aerosol optical properties, fog water-chemistry, and vertical thermodynamical structure to describe the environmental stability in which fog develops. An operational modeling framework, the WRF model, was set up to provide fog predictions during the measurement campaign. These field observations helped to interpret the strengths and deficiencies in the numerical modeling framework. Four scientific objectives were pursued: (a) life cycle of optically thin and thick fog, (b) microphysical properties in the polluted boundary layer, (c) fog water chemistry, gas/aerosol partitioning during fog life-cycle, and (d) numerical prediction of fog. This paper presents an overview of WiFEX and a synthesis of selected observational and modeling analyses/findings related to the above mentioned scientific topics.

Radiometer-derived thermodynamical properties of Dense fog, Haze and Clear events during the Winter Fog Experiment	Narendra Gokul Dhangar	IITM

During the Winter Fog Experiment, a Microwave Radiometer was installed at IGI, Airport, New Delhi. A total of 35 events are analysed, including 12 dense fog (Vis <200m), 12 haze and 11 clear. Radiometer-derived cloud liquid water, relative Humidity and Temperature and their characteristics during the dense fog, haze and clear events are presented in this study. During the mature phase of the dense fog, maximum cloud liquid water is available up to 300m with 0.30 g/m3. During haze events, cloud liquid water is observed up to 100 m vertically with 0.01 g/m3. A radiometer-derived relative humidity was 100% in a mature phase of dense fog, maximum relative humidity measured during the haze events is up to 80%, whereas relative humidity in the morning of clear events is observed to be up to 70%. In most of the dense fog events, the minimum temperature is observed at 6 Celsius, in haze 10 Celsius, and in clear events, it is 12 Celsius. An automatic weather sensor measured minimum temperature, and relative humidity near the surface are in close agreement with the radiometer retrieved values. A microwave radiometer-derived temperature and relative humidity values using brightness temperature based on the algorithm are close to the measurement of an automatic weather sensor.

Visibility prediction – update on Vera	Bernard Claxton	Met Office

Vera is a visibility diagnostic scheme used to predict fog. Although native to the Met Office's UM and run within DRUM, Vera can be ported to other models e.g. WRF-Delhi, or can be coupled to the MONC LES model as a standalone scheme. Using synthetic noise to mimic the sub-grid variation within modelled temperature and humidity fields, Vera generates an ensemble of diagnosed visibilities used to compute probabilistic output, currently producing visibility centiles and visibility threshold probabilities.
This talk describes recent progress with Vera and a survey of implementation to date. Possible future developments will be discussed, including thoughts on the challenge of interpreting Vera's output.

Sensitivity of the VERA-simulated visibility over Delhi to its meteorological input parameters	Gayatry Kalita	IITM

The 'Visibility Employing Realistic Aerosols' (VERA) model of the UK Met Office has been utilized for visibility prediction over Delhi. The model calculates visibility by allowing aerosols to participate in the fog-droplet formation processes. The VERA-simulated visibility in Delhi during winter with the 'log-normal generic Mie scattering' configuration showed a large deviation from the observations. Sensitivity tests with input meteorological parameters namely specific humidity (q), liquid water mixing ratio (qcl), and dry aerosol mixing ratio (am) revealed that the predicted visibility is highly sensitive to these parameters. Comparative analysis of the prescribed dry aerosol size distribution in VERA with the corresponding measurements carried out under the Winter Fog Experiment (WiFEX) campaign over Delhi identified the large difference in them. While WiFEX measurements show a multimodal dry aerosol size distribution over Delhi, VERA prescribes six different uni-modal configurations. In this study, we have initiated modifications in VERA by introducing a new observationally constrained dry aerosol size distribution for Delhi. We estimate the PM2.5 size distribution from the measured PM2.5 mass mixing ratio by employing the multi-modal log-normal size distribution described by Hess et al., (1998). The forthcoming challenge is to make the new estimated PM2.5 size distribution formulation online within VERA.

Understanding factors influencing MetUM forecasts of fog over India: An irrigation perspective	Srinivas Reka	University East Anglia

Dense fog regularly impacts Delhi during the wintertime severely affecting road and rail transport, the aviation-sector and human health. The performance of the Met Office Unified Model (MetUM) with a recent development in the irrigation parameterization at 1.5km horizontal grid-length, is evaluated during a fog event in January-2016. The Winter Fog Experiment (WiFEX) was conducted to study the origin of fog formation during 22nd – 24th January, 2016 at the Indira Gandhi International Airport (IGIA-Palam), Delhi, India. Analysis shows that the observed visibility dropped below 100m and relative humidity (RH) reached 100%, marking the onset of dense fog during 22nd – 24th January. We have conducted irrigated and non-irrigated experiments to improve our understanding of the important processes driving widespread fog events in the IGP (includes Delhi) region. The irrigated crop-land area provides the additional moisture and the consequent changes to the surface energy budget cause the widespread dense fog to be more persistent and result in the advection of moisture into Delhi and beyond. Accounting for irrigation leads to visibility being well simulated throughout the dense fog period on 22nd January 2016. Other parameters are also simulated well compared to non-irrigated simulations.

Sensitivity of fog simulation over Delhi region to the latest LULC in WRF Model	Utkarsh P. Bhautmage	IITM

The Indo-Gangetic plains (IGP) region spreading across the northern parts of India is prone to fog formations during the winter season. The increasing dense fog episodes over the past few decades due to dipping temperatures and negative anomalies in the region are creating concern for the aviation and transportation sectors, particularly at the Indira Gandhi International airport (IGIA) in Delhi. To avoid the socioeconomic losses incurred due to the fog phenomenon as well as from the public health point of view, the accurate forecasting of the spatial and temporal extent of the fog is crucial with specific attention to its onset and dissipation timings in the urban areas. Several studies have reported that fog frequency trends are affected due to the changes associated with urban meteorological parameters. In this study, the sensitivity analysis of the fog simulations to the land-use and land-cover (LULC) has been demonstrated together with the latest released sentinel satellite data updated LULC in the Delhi region. In the future, it is planned to implement the sentinel data-based LULC with the GLOBUS dataset of the urban morphological parameter (i.e. building height data and others) to improve the fog forecasting with the recently developed high-resolution WRF-UACM (Weather Research and Forecasting - Urban Asymmetric Convective Model) of 1 km grid resolution (Dy et al., 2019, Bhautmage et al., 2022), which has shown promising results when applied to a dense urbanized Pearl River Delta (PRD) region in southern China. It is expected that fog operational forecasting will improve significantly with this novel model which is based upon the urban convective processes and requirement of a few fundamental urban morphological parameters.

Understanding the role of aerosol-chemistry for Delhi fog simulation using particle-based Eulerian-Lagrangian model	Moumita Bhowmik	IITM [online]

With the changing climate, the study of fog formation over Northern part of India is essential and needs of the hour, as the nature of fog has changed due to impact of complexity of natural and anthropogenic aerosols. Chemical and physical properties of dry condensation nuclei (CN) influence the formation of fog and thus visibility over Delhi, India. The presences of ample water vapor in the air, microphysical and thermodynamic property of dry CN are crucial for the occurrence and sustenance of fog. The visibility parameterization is depending on the number of fog droplets. The aerosol particle and conversion of aerosol to fog droplet, which requires external nuclei for water vapor to condensation, is controlled by the processes of condensation or diffusional growth. Here, we have used Eulerian-Lagrangian particle-based model to simulate the diffusional growth of droplets. The condensation process is controlled by the solute effect (Raoult's effect) and the curvature effect (Kelvin effect) in Köhler curve and both processes are considered in the present study. Droplets with higher solute concentration have lower critical supersaturation values. Thus, hygroscopicity (κ), which is highly related to the activation of cloud condensation nuclei (CCN), takes into account the contribution of dry aerosol particles to fog droplet formation. The κ-Köhler theory combining the Kelvin's equation and the Raoult's law are used for the activation of a deliquesced aerosol particle, which is forming an aqueous solution droplet into a smaller cloud droplet. Hygroscopicity is essential in numerical model for the fog and visibility prediction as microphysical properties of fog are regulated by aerosol chemistry. It is concluded that the complexity in fog and visibility forecasting is found to be high due to multiple factors having a role at multiple levels. We may propose a revised visibility parameterization over Indian subcontinent.

Progress towards Implementing a Vertically Distributed Urban Canopy in the Unified Model	Jon Shonk	Met Office [online]

Given the rise in global urban population, the need to provide realistic weather forecasts and climate projections within cities is more important than ever. With increases in supercomputer processing speed and power, neighbourhood-scale forecasts are becoming tractable with the potential to provide meteorological information on scales smaller than 1 km, allowing greater capacity to predict weather hazards in very localised areas.

To achieve such aims, there is a need to develop our urban surface schemes. MORUSES, the urban scheme in the Met Office’s Unified Model (UM), parametrises urban–atmosphere exchange of momentum, scalar flux and radiation using a 2D street canyon approach with separate surface energy balances for street canyons and rooftops. The scheme uses a roughness length approach, meaning that the surface may only interact with the atmosphere via its bottom level. This is a crucial shortcoming – urban canopies should be able to influence the state of the atmosphere throughout their vertical extent.

In this presentation, we present an update on our plan to implement a fully distributed prognostic urban canopy into the UM. Our initial work aims to improve representation of the momentum budget by including a vertically distributed drag profile within the urban canopy. To achieve this, we first implement a raised blending height that varies with atmospheric stability, meaning that the surface is no longer coupled to the bottom level of the atmosphere model. Beneath the blending height, as a first step, diagnostic velocity and scalar profiles are calculated from analytical solutions.

We present our progress and results so far, including model simulations with the raised variable blending height in place in the model. We also discuss methods to determine the horizontal scale of surface inhomogeneity, which is required to calculate the blending height, and present work to create an original method to determine this scale based on thresholds in spatial decorrelation.

PLENARY 8: Improving prediction of visibility and fog over the Indian subcontinent

Wednesday 1st March 2023

Operational Probabilistic Fog Forecast Using Ensemble Prediction System: Development, Verification and Challenges	Avinash N Parde, IITM

The spatial and temporal variability of fog is a well-known challenge in fog forecasting. Ensemble forecasts capture this variability by representing uncertainty in the initial/lateral boundary conditions (ICs/BCs) and model physics. The present study highlights a new operational Ensemble Forecast System (EFS) developed by the Indian Institute of Tropical Meteorology

(IITM), Pune, to predict fog over the Indo-Gangetic Plain (IGP) region using the visibility (Vis) diagnostic algorithm. A WRF model with a horizontal resolution of 4 km is initialized by 21 ICs/BCs in the EFS framework. Control (CNTL) and ensemble-based fog forecasts have been compared to demonstrate the advantages of probabilistic fog forecasting. Forecasts are verified using fog observations collected at the Indira Gandhi International (IGI) airport during the winter months of 2020-2021 and 2021-2022. The results show that with a probability threshold of 50%, the ensemble forecasts perform better than the CNTL forecasts. A Hit Rate of 0.95 and a Critical Success Index of 0.55 are relatively promising skill scores for EFS, as are False Alarm Rates and Missing Rates, each of which stands at 0.43 and 0.04. Overall, EFS correctly predicted more fog events (37 out of 39), compared to CNTL's forecasts (30 out of 39). Further, EFS has a significantly lower error in predicting fog onset and dissipation than CNTL (mean onset and dissipation errors of 1 h each)

Sensitivity of fog over Delhi to aerosol concentrations	Andrew Ross, University of Leeds

Large eddy simulations using the Met Office-NERC Cloud Model (MONC) couple with the Met Office SOCRATES radiation scheme and CASIM microphysics scheme have been conducted based on several case studies of fog over Delhi observed during the WIFEX experiment. The recently developed VERA visibility diagnostic is used to predict visibility. The baseline simulations using aerosol values typical of Delhi is reasonably successful in capturing the timing and development of the fog. For each case study sensitivity tests have been conducted varying aerosol mass and number to understand the impact of aerosol concentration on the fog development. For low concentration (up to about 20% of the baseline values) increased aerosol leads to thicker fog, as expected. For higher concentrations more typical of Delhi however further increases in aerosol actual reduce the liquid water in the fog, suggesting that Delhi maybe in a regime where aerosol suppresses fog. If true, this may have implications for interpreting recent trends in fog over Delhi and also for assessing the impact of any policies to improve air quality and reduce aerosol.

Impact of Aerosol-cloud interactions in simulating extreme weather events during winter season over Delhi	Anurose TJ, NCMRWF

Aerosol-cloud interactions play a critical role in the formation and evolution of fog and precipitation events. In the present study, fog and precipitation cases are investigated over Delhi using DM_Chem model during the winter season. DM_Chem includes the cloud-aerosol interactive microphysics scheme (CASIM) and the United Kingdom Chemistry and Aerosols (UKCA) model for a detailed treatment of aerosol-cloud interaction. Due to the relative role of both aerosols and relative humidity (RH), the model produces reasonably well visibility forecasts in many fog cases under different environmental conditions. However, the simulations show a strong dry RH bias and absence/quick dissipation of fog, especially during the dense fog cases, and the magnitudes of visibility are overestimated. To improve the RH bias, irrigation parameterization is planned. The aerosol activation approach of the model will be further explored to improve the onset and evolution of fog. Hourly RADAR rain evaluation for the precipitation case indicates that the intensity of the precipitation is captured more accurately in the presence of UKCA aerosols. A detailed evaluation is ongoing and the main outcome will be presented

PARALLEL SESSION 4: Impact based forecasting
Wednesday 1st March 2023

Impact Based Forecasting for Intense Precipitation Events in Uttar Pradesh: Recent Developments, Status, Challenges & Future Perspectives	Atul Kumar Singh	IMD

Phenomenal improvement has been observed in weather forecasting and prediction skills with great benefit from the introduction of Early Warning Systems (EWSs) in the recent past. Introduction of Conceptual Multi-Hazard Impact Based Forecasting and Warning services by WMO resolution vide WMO-No 1150 with the aim to bridge the gap between scientific community, different stakeholders and end user has brought an exemplary progress towards the last mile connectivity in most appropriate & understandable format by connecting & increasing synergies between four fundamental components of effective EWSs viz. Risk Knowledge, Monitoring & Warning, Dissemination & Communication and Response Capability with inception of cross cutting component in the form of Community Centric Bottom-up Approach. IBF has brought a paradigm shift in the forecasting jargon by switching from Static system (Seamless Forecasting) to Dynamic system (MHIBF), which has proven to be a great initiative towards 'TRANSLATING HAZARD INFORMATION INTO IMPACT SCENARIOS'.

Uttar Pradesh comprising of 75 districts broadly classified into two meteorological subdivisions & nine Agro-climatic zones. Each of these region have different climatic zones/features owing to its complex physiographical characteristics due to which this region is one of the most vulnerable part of the Indian subcontinent pertaining to various severe/disastrous natural hazards like Heat Wave, Cold Wave, Dense Fog events, intense & severe convective storms; but floods/flash floods caused due to Heavy/Intense rainfall episodes often result into high socio-economic impacts due to its peculiar geophysical settings in the vast Indo-Gangatic flood plains of multiple river basins. This region is very often prone to furry of monsoon and the floods in Uttar Pradesh are acute and unique so far its extent, duration and magnitude are concerned with most of its eastern part is susceptible to flood damage.

In this study methodology for real time operational IBF for few recent cases have been discussed. This study discusses about the potential challenges and opportunities offered by this approach in the decision-making workflow in an operational context. The methodology may be classified into three principal aspects. The first & foremost input comes from the collection of detailed Meteorological/Geophysical/Physical/Socio-Economic/Hazard/ Exposure/Vulnerability/Impact data in order to create a consolidated Digital Data Repository in the form of Comprehensive District Profile Database for each district. The second part comes in the form of computation of numerical thresholds for different impact scenarios & preparation of Impact/Risk matrix accordingly based on two subjective approaches viz. Threshold Method (Elements: Meteorological Thresholds, Occurrence Probability & Expected Impact) aided/supported by Qualitative Combinational Method incorporating Generalised Conventional IBF. Final, but most vital part is the creation of suitable Response Matrix for different Impact/Risk scenarios to include exposure & vulnerability factors qualitatively and to quantify the uncertainties in the first two parts for proper Risk Assessment and Decisive Action in consultation with Disaster Managers & different line departments.

The present approach goes one step further and comes up with a provisional qualitative cum quantitative Impact Based Warning products on zonal/regional/local basis depending upon the spatio-temporal scale of the event starting from cluster of districts classified on the basis of similar climatic/hazard/vulnerability profile to the individual district/sub-district scale profile with specified colour codes depending upon the scale of exposure & vulnerability pertaining to the specific type of hazard/multi-hazard in this region of the country, which may ultimately result in better contingency planning with community centric bottom-up approach. This approach would also improve the objective evaluation of responsibilities of forecasters and decision makers in the EWS context. Additionally, IBF can further contribute towards Community Based Disaster Risk Reductions, Resilience & Response (CBDRRRR) mechanism through common situational awareness & behavioral recommendations (BRs) in order to achieve the prescribed seven Global Targets of

Sendai Framework (2015-2030) with four (04) well defined Priorities for action towards Disaster Risk Reduction.

Overall, this study aims to offer a first insight into the impact-based forecasting and warning services with various sectoral applications in this region to trigger further research and project developments with empirical justification for the added expense and time associated with the more detailed hazard warnings.

Assessment of impact based forecast issued for the state of Andhra Pradesh during 2022	K. Sagar	IMD

India being an agricultural country, the socio economy of the country depends on the monsoon seasonal rainfall. India witnesses both southwest (June-September) and northeast (October-December) monsoon seasons. However, monsoon rainfall has large spatial distribution from region to region. On the other hand south west monsoon covers the entire country while the north east monsoon covers only the southern peninsular states which covers both monsoon seasons. Andhra Pradesh (AP) is one among them. It is also one of the most vulnerable states in India to multiple natural hazards like cyclones , extremely heavy rains and floods, thunderstorms and lightning and heat waves due its peculiar geographical location. The state has got varied physical features with coastal line of 974 Kms along Bay of Bengal, Eastern Ghats, Hills, forest covers, 2 major rivers along with 19 minor rivers. The impact of these hazards plays an important role in the lively hood of the people. Therefore, early warning of these climate hazards and vulnerability are essential and highly helpful for mitigation in the state. Meteorological Centre Amaravati (here after MCA), one of the state weather forecasting centres of India Meteorological Centre, is responsible to issue weather forecasting and warnings for the state. Now, MCA started issuing Impact Based Forecast (IBF) for the state based on its climatology, synoptic features, vulnerability and numerical weather prediction models. Based on 2011-2020 data, it is seen that few districts of the state such as East Godavari and Yanam,Visakapatnam and Srikakulam during southwest monsoon season and districts like Nellore, Prakasam , Chittoor during north east monsoon are highly prone for heavy/ very heavy / extremely heavy rains. Districts such as Nellore, Prakasam, Guntur, Krishna,East Godavari, Visakapatnam,Vizianagaram and Srikakulam are very highly prone to be affected by floods. The synoptic features during south west monsoon that gives heavy/very heavy/extremely heavy rainfall especially over north coastal AP are generally due to low pressure, depression with over north Andhra coast or over North west and adjoining West central Bay of Bengal off south Odisha and north Andhra coasts and the associated cyclonic circulation tilting south west wards with height, East-west shear zone or trough over north coastal Andhra Pradesh. During north east monsoon, low pressure ,depression, cyclones, easterly waves/trough with strong wind surge at lower levels give heavy /very heavy/extremely heavy rains over southern districts of south coastal Andhra Pradesh and Rayalaseema.

In this study, the assessment of district-wise IBF issued during heavy rainfall events over AP during south west and northeast monsoon seasons in 2022 were done. Multi number of attributes has been selected from each district based on their physiology and frequency of vulnerability with respect to heavy/very heavy/extremely heavy rainfall events. Impacts expected and action to be taken were issued district-wise with specific to the important location. Based on that, mitigation plan was taken care by the SDMA. During June – Sept ‘2022, the no. of days of realized extremely heavy rain/very heavy /heavy rain were 2,15,56 respectively. Flooding/inundation,roads damages and and crop damages were reported. Realised rainfall and the available media reports on damages were used to verify the IBF. More results will be presented during the workshop.

Assessment of Flood Risk and Enhanced Resilience for frequent floods impacted by high discharges of river in the upper catchments and associated Heavy rainfall in the North Bihar, India	Ananda Shankar	IMD

Impact based forecast (IbF) for heavy rainfall in Karnataka	Geetha Agnihotri	IMD **10-min
Heavy Rainfall Events Over Chhattisgarh: Understanding its Impact	Gayatri Vani Kanchibhotla	IMD **10-min [online]
Impact based forecast (IbF) for heavy rainfall in Bangalore	A Prasad	IMD **10-min [online]
Impact-based Very Heavy Rainfall Warning for Bhopal during monsoon 2022	R Balasubramanian	IMD [online]

IMD has started issuing Impact Based Weather Forecast (IBF) for application in various sectors since 2021. IBF comprises of district-level weather warning for anomalous weather events in text and colour codes and also likely impact on the society & actions suggested.
During the monsoon 2022, Madhya Pradesh state experienced delayed arrival of monsoon rains but monsoon picked up with excess and heavy rains later on. IMD had also issued press release on 22nd August with isolated heavy to very heavy rainfall with extremely heavy rainfall on 22nd August 2022 for West Madhya Pradesh where Bhopal is located.
In the present study, impact-based weather forecast issued for Bhopal city during monsoon 2022 has been analysed.
Rainfall activity was vigorous during monsoon 2022 since July. Very Heavy rainfall occurred in Bhopal on 22nd August 2022. On 23rd August also, rainfall activity was vigorous in Bhopal.
IBF for very heavy rainfall (12-20 cm) has been issued with red alert for Bhopal for 22nd August 2022. Impact of very heavy rainfall like waterlogging, flooding and damage to vulnerable structures has been issued while issuing the forecast. Impact on the crops has also been issued for Bhopal.
Issuance of very heavy rainfall has been validated with realized rainfall for the period. Around 400 mm of rainfall has been received during two successive days (191 mm on 22nd August and 209 mm on 23rd August).
During these two days, rainfall activity along with strong winds continued for more than 30 hours which led to power disruption and inundation in the roads which led to difficulties in relief measures that followed after the heavy rainfall event. Schools have been closed and communications lines had also been disrupted for some period.
Receipt of such excess rainfall led to disruption of various structures, waterlogging, uprooting of more than 200 trees etc., in Bhopal as reported by State Disaster Management Agency (SDMA) in Madhya Pradesh. Power outage has been reported in some pockets for more than 12 hours due to damage of power infrastructure.
Crops like soyabean and maize at vegetative stage have been damaged due to waterlogging conditions. Orchard trees have also been affected. Agromet Advisories have been issued to prevent/minimize the damage.

Impact Based Forecast Issued by IMD for the Intense Rainfall/Snowfall Spell over Northwest India during 05th-09th January, 2022	Krishna Mishra	IMD

Two Western Disturbances (WDs) in succession affected Northwest India during 05th- 09th January. The first WD caused widespread rainfall with isolated heavy rainfall over the Western Himalayan Region (WHR) on 06th and the second WD caused widespread rainfall with isolated hailstorm and isolated heavy to very heavy rainfall during 07th-08th January. These successive

WDs caused isolated heavy to very heavy snowfall activity over north Pakistan, Kashmir, Gilgit, Baltistan, Ladakh, Muzaffarabad regions leading to blockade of roads and landslides over these areas which caused loss to lives and public property. As per the media reports, 22 tourists in the north Pakistan region were frozen to death due to snowfall by this intense WD.
The sky remained overcast and there was no sunlight over Northwest India (NWI) for straight 3 days during 7th-9th January. After the passage of this WD lower level easterlies continued for 2-3 days due to which lower levels clouds over Northwest India prevailed for subsequent one week which resulted into Severe Cold Day conditions over the region and overcast skies upto 16th January. Sky remained generally cloudy over the plains of NWI during the period 05th-16th January 2022. India Meteorological Department (IMD) had started issuing Press Release on this event from 29th December 2021 itself i.e. with a lead time of about one week.
Timely dissemination of heavy rainfall/snowfall warnings for the WHR and hailstorm warnings for the plains of NWI enabled timely actions by State & Central Disaster Management Authorities to save losses to the human lives and property.

A methodology for computation of district wise heavy rainfall impact score for Rajasthan	Radheshyam Sharma	IMD **10-min

Rajasthan is located in North-western parts of India and characterised by low monsoon rainfall with high variability. The state has varying topographic features, a major part of the state is dominated by parched and dry region. The impact of heavy rainfall is mainly depends upon five parameters; namely amount of rainfall, topography, nature of soil and vegetation, structure of houses, population density and percolation of the surface. Each district has unique impact of rainfall due to the diverse nature of these parameters.
District wise geographical, physiographical and socio economic data have been collected and analysed. Impact score of each parameters have been classified into four categories and accordingly assigned a weightage; minimal (0), minor (0.33), significant (0.67) and severe (1.0). The rainfall is the chief parameter for adverse impact over a particular district. The impact score for rainfall has been assigned 0 for moderate, 1.0 for heavy, 2.0 for very heavy and 3.0 for extremely heavy rainfall. One third impact of previous day rainfall has also considered. The cumulative impact score describe the severity level of heavy rainfall impact. The method has been validated with extremely heavy rainfall spell during 31st July to 04th August 2021 in Rajasthan. It is observed that cumulative impact score below 2.0 is considered as minimal, 2.0-3.0 as minor, 3.0-4.0 as significant and above 4.0 is considered as severe.

Analysis of Heavy Rainfall events during Southwest Monsoon 2022 over Gujarat State as an input tool for Impact Based Forecasting: A Case Study	Parul Trivedi	IMD **10-min

Improving Impact Based Forecast of Heavy rainfall in Kerala	V.K.Mini	IMD **10-min [online]

India Meteorological Department, Thiruvananthapuram implemented district-wise impact-based forecasting (IBF) for heavy rainfall since 2021 and IBF for thunderstorm since 2022l. By implementing IBF, Meteorological services can provide critical information of weather forecasts and warnings to help mitigate life-threatening impacts by heavy rainfall, thereby enabling government authorities and general public to take action that saves lives, livelihoods and property. IMD Thiruvananthapuram devised a methodology for issue of IBF for heavy rainfall over all the 14 districts of Kerala since Southwest Monsoon season (SWM) and Northeast Monsoon season (NEM) 2021, on the similar lines of implementing IBF for two major cities in Kerala during 2020. 17 years' historical impact data (2004-2020) were collected from media reports corresponding to the days of occurrence of heavy rainfall event and an impact matrix and a risk matrix based on rainfall threshold value are prepared separately for all 14 districts as a part of the risk assessment. As a pioneer in issuing IBF, we assessed our performance during last two years by a verification method based on the contingency table approach, which served as the starting point for examining the strengths and weakness of IBF and has given information about the skill of the forecast as well as the type of errors that occurred in the forecast. During 2021, the average percentage correctness was 78%, with probability of detection 0.6 and a skill score of 0.3, but false alarm rate stood at 0.54 and missing rate at 0.4, but PC improved to 82% during 2022.

PLENARY 7: Impact modelling and forecasting techniques

Wednesday 1st March 2023

Impact-Based Forecasting and Warning: Methodology, and Implementation for NEast India	Arun Kumar VH, IMD

Meteorological services are changing their usual way of providing simple weather warnings toward risk-based warnings, termed "Impact-based Forecasting" by WMO, which integrates the likelihood and severity of impacts due to severe weather (WMO, 2015; Silvestro et. al., 2019). Impact Based Forecasting (IBF) helps the public and the communities to prepare appropriately for the threats expected from severe weather events (WMO, 2015). IBF can lead to an improved understanding of forecasts (Potter et. al., 2018) and may increase peoples' intention to take protective measures against severe weather (Casteel, 2016; Weyrich et. al., 2018). This present study deals with a methodology for the impact-based forecast (IBF) for the state of Assam, in connection with heavy rainfall events. The past experiences of various impacts of heavy rainfall events and their severity were studied and documented for Assam to implement IBF in the operational mode. Based on the topographical as well as physiographical data, the districts of Assam were segregated into Hilly as well as Plain districts. An impact matrix was prepared for these clusters of districts and presented in the current study as a part of the risk assessment. From the historical data, the days of impact were identified, and rainfall that led to the impacts is also collected. The hazard thresholds which created various impacts like landslides, and flooding were estimated for these clusters of districts, and an impact matrix corresponding to various impact levels is formulated. All the collected impact events are tabulated in the impact matrix under various levels, namely, minimal, minor, significant, and severe. Heavy rainfall in a single day may not create so much impact and may depend upon the previous day's rainfall too. To account for this factor, five-day cumulative rainfall up to the day of the event is calculated, the cumulative rainfall is categorized into different ranges, and the level of impacts is segregated under the respective rainfall ranges. In this way, a lookup table for the impact category against the hazard threshold is generated, which is being utilized for issuing IBF over different clusters of districts. The same methodology is adapted for the preparation of the impact matrix for the rest of the states in North East India. Regional Meteorological Centre, India Meteorological Department, Guwahati is operationally issuing IBF for all the States in Northeast India as well as for Guwahati city since 2020. It is planned to fine-tune the impact matrix by collecting more historical impact data, exposure data, vulnerability data, etc.

Satellite derived impacts of flooding in Bihar, India	Barbara Hofmann, HR Wallingford

India, and Bihar in particular, regularly experience severe flooding. Measurements of flood impact are needed both to act as verification data for the development and testing of impact-based forecast models and to enable efficient targeting of relief resources
We present research into using earth observation data to estimate the impact of flooding on agriculture and the built environment in Bihar, India in 2020. Heavy rainfall hit northern Bihar in July 2020 causing wide-spread flooding. Villages were flooded or cut-off and hundreds of acres of Kharif crops were destroyed.

We generated flood extent and duration from synthetic aperture radar (SAR) data over a five month period following the flood onset, and combined these with Normalised Difference Vegetation Index (NDVI) data, derived from multispectral satellite data, OpenStreetMap data (OSM) and population data sets to derive impact. For disaster management the short-term impact on the built-environment is particularly useful. We identified roads blocked by flooding and developed an index which enables us to estimate the impact on settlements in terms of access to key facilities such as hospitals, and update this as time progresses. The impact on agriculture is long-lasting with flood water remaining for up to four months in areas, encroaching on the sowing period of the following Rabi season. Our results are presented on our prototype website which allows us to interrogate areas in detail.	
Impact based forecasting of heavy rainfall over Maharashtra	Nitha.T.S, IMD

PARALLEL SESSION 5: Improving models using observations
Wednesday 1st March 2023

Role of mean dynamic topography on the satellite-derived sea level anomaly data assimilation	Imranali M Momin	NCMRWF

The mean dynamic topography (MDT) is a reference for the assimilation of satellite-derived sea level anomaly (SLA) which is added to the SLA observations before assimilation. The estimation of MDT is possible with the development of gravity missions which computed the geoid height above the reference ellipsoid. In this study, we have used the two different MDT observations to understand their relative impact on the assimilation of altimeter-derived SLA observations. The sensitivity experiments with two different MDT have been carried out using the Nucleus European Modeling of Ocean (NEMO) based variational data assimilation system called NEMOVAR in the National Centre for Medium Range Weather Forecasting (NCMRWF). Two different experiments are NASA-R and CNES-R based on the NASA and CNES MDT used as reference data respectively. Both experiments assimilated the In-situ observations of temperature, salinity, and satellite-derived SST, SLA, and sea ice observations. Both experiments were run from the 31-May-2016 up to one month with surface boundary fluxes from the NCMRWF Unified Model. The analyzed temperature, salinity, Mixed Layer Depth (MLD) and Sea Surface Height (SSH) were compared to understand the relative impact of MDT. The result shows that the reference MDT affects the initial assimilation cycle's through the analyzed temperature and salinity profile. We also show the comparison of analyzed temperature, salinity and SSH from both experiments with observations in terms of mean error and Root Mean Square Error (RMSE).

Atmosphere and Land Data Assimilation in NCUM-R NWP System and its benefits	Ashish Routray	NCMRWF

Several parts of Indian sub-continent receive extremely high precipitation, many a times in a year, under the influence of organized mesoscale convective systems (MCSs) embedded in large scale synoptic systems. The rainfall amounts of 100–300 mm or more in a day are not un-common. The accurate quantitative forecasting of precipitation, especially during severe weather episodes associated with systems such as monsoon lows/depressions, tropical cyclones etc. is challenging. Since weather forecasting is now largely depends on the guidance provided by Numerical Weather Prediction (NWP), it is essentials to use state-of-the-art high resolution NWP models with advanced atmospheric data assimilation capabilities. Many recent studies suggest that the performance of the NWP system can be further improved by providing realistic representation of land surface conditions, especially soil moisture. It is known that soil moisture is a key driver in the exchanges of water and heat fluxes between the ground and the atmosphere.
The present study aim is to understand the importance of high-resolution assimilation-forecast system for accurate forecast of the heavy rainfall events associated with various weather systems. This study focuses on the impact of initial conditions on the NWP forecast. A high resolution (4 km) regional modeling systems based on Unified Model, NCUM-R (NCMRWF Unified Model- Regional) with a four-dimensional variational data assimilation system (4D-Var) is used in this study. Observing System Experiments (OSEs) have been carried out to assess the impact of the high-resolution atmospheric observations such as radar reflectivity and radial velocity, various satellite observations on analysis and forecasts. Impact of the use of ASCAT soil moisture estimate in the Land Data Assimilation System, through sEKF based LDAS, on the high-resolution forecast are also studied. OSE studies indicates that the assimilation of radar and satellite observations (atmosphere) and ASCAT soil moisture have beneficial impact on the simulation of heavy rainfall events.

Land Information System (LIS) with JULES and data assimilation impact on energy fluxes	Hashmi Fatima	NCMRWF

The accurate quantification of land surface, water and energy cycles is important for a wide range of applications including weather and climate modeling and initialization, agricultural and water management and estimation of hydrological hazards such as droughts and floods, among others. The Land Information System (LIS) developed by Hydrological Sciences Laboratory at NASA's Goddard Space Flight Center, is a software framework for high performance terrestrial hydrology modeling and data assimilation developed with the goal of integrating satellite and ground-based observational data products and advanced modeling techniques to produce optimal fields of land surface states and fluxes. LIS has the capability to plug and play of any kind of land surface model (Noah, Cable, VIC, CLM, JULES etc.). LIS with JULES land surface model has been used here. Experiments have been done with and without data assimilation to see the impact. It has been observed in the model output that data assimilation has significant impact on energy fluxes.

Multi-year impact of observation in a UM based operational global NWP system	Sumit Kumar	NCMRWF

National Centre for Medium Range Weather Forecasting (NCMRWF) global Unified Model (NCUM-G) uses hybrid 4D-Var data assimilation scheme for the assimilation of observations. The Global Observing System Network, comprising of satellite and in-situ measurements, plays a crucial role in maintaining and enhancing the accuracy of Numerical Weather Prediction (NWP) Systems. Currently, NCUM-G uses observations from number of low earth orbit (LEO) and geostationary satellites and several conventional observations (Surface and Upper-air). As millions of observations are being assimilated though every Data Assimilation (DA) cycle, DA diagnostic plays an essential role to monitor, understand and tune the system. The adjoint based forecast sensitivity to observation impact (FSOI) diagnostic method is employed here at NCMRWF operationally to assess the impact of all assimilated observations in the global NWP system. FSOI measures the amount by which an observation type reduces the short-range forecast error (within a system containing all observation types). Here, we studied the impact of all assimilated observation in NCUM-G from 2018 to 2022, especially during Indian summer monsoon period. The largest overall contributions to 24 hr forecast error reduction come from ATOVS (17% of total impact) and IASI (16%) during this period. These are followed by geostationary atmospheric motion vectors (AMVs) (11%), radiosonde (9.5%) and aircraft reports (9%). Space-based observations contribute ~75% of the beneficial impact on the 24-hr forecast. Moreover, specific observation impacts statistics for various region, separate channels or separate satellites etc will also be presented.

Assimilation of Indian DBNet ATOVS radiances at NCMRWF	Srinivas Desamsetti	NCMRWF

NCMRWF receives regional DBNet (Direct Broadcast Network) data from low earth orbiting satellites from India and other parts of the world, mainly through Global Telecommunication System (GTS), EUMETSAT's ATOVS Retransmission Service (EARS) and Regional ATOVs Re-transmission Service (RARS). NCMRWF has taken initiative to receive DBNet data from India. In India two DBNet stations are installed, one at INCOIS, and the other at NRSC located in Hyderabad. NCMRWF regularly receives level-0 data from these DBNet stations with a latency of 1 hour. NCMRWF developed in-house software to process these level-0 data and to generate level-1b to level-1d datasets. In this paper, the ATOVS DBNet data is assimilated along with conventional datasets (Surface, Sonde, Aircraft, Scatwind, Satwind) in order to understand the impact of this regional DBNet data in the NCMRWF operational data assimilation system. The impact these data is presented by taking a case study of “SITRANG” cyclone which had genesis over Bay of Bengal with life cycle from 22 to 25 October 2022. Two experiments are designed one with ATOVS DBNet (EXP) and other with conventional (CNT) data. The results show that DBNet data has very good impact. Detailed results will be discussed during the conference.

Impact of Assimilation of Radar Reflectivity and Radial Velocity on Simulation of Precipitation Events over Indian Region	Devajyoti Dutta	NCMRWF

Indian sub-continent receives significant amount of rainfall during active phase of the Summer Monsoon season. Accurate prediction of high rainfall events using NWP model require improved initial conditions, prepared using high resolution observations with sophisticated data assimilation system. More and more Doppler Weather Radar (DWR) observations became available to the user

community over Indian region, in recent times. The prime objective of this study is to evaluate the impact of the assimilation of Indian multi-DWRs reflectivity and radial velocity on the simulation of high rainfall events occurred during an active phase of summer monsoon(June 2022) using high-resolution (4 km) regional NCUM system (NCUM-R). Two sets of assimilation-forecast experiments, CTL and RAD, with different initial conditions have been carried out. CTL analysis has been prepared by assimilating conventional and satellite observations whereas RAD analysis used high resolution DWR observations (radial winds and reflectivity) in addition to the observations included in the CTL analysis. The high-resolution analyses are prepared for both the experiments, using an advanced four-dimensional variational (4D-Var) data assimilation system.
The results of the study show that the assimilation of DWRs reflectivity along with radial velocity has a positive impact on the simulation of rainfall events. Root mean square error (RMSE) in wind and moisture forecast in RAD experiment is less compared to CTL experiment. The amount and orientation of rainfall pattern is better simulated by RAD than that by the CTL. Statistical skill scores of rainfall forecasts, for different thresholds, are significantly improved with the use of radar observations in the model initial conditions. This study shows that assimilation of Indian DWRs reflectivity along with radial velocity observations have a beneficial impact on high-resolution NWP, especially high rainfall forecast.

PLENARY 10: Improving models using observations
Thursday 2nd March 2023

Assessment of short-range forecast atmosphere-ocean cross-covariances from the Met Office coupled NWP system	Amos Lawless, Uni. Reading

As part of the design of future coupled forecasting systems, operational centres such as the Met Office are starting to include atmosphere-ocean interactions within the data assimilation system. To understand the potential benefit of further coupling in the data assimilation scheme it is important to understand the significance and variability of any cross-correlations between atmosphere and ocean short-range forecast errors. In this work we examine atmosphere-ocean cross-covariances from an ensemble of the Met Office coupled NWP system for December 2019, with particular focus on short-range forecast errors that evolve at lead times up to 6 hours.
We find that significant correlations exist between atmosphere and ocean forecast errors on these timescales, and that these vary diurnally, from day to day, spatially and synoptically. Negative correlations between errors in sea-surface temperature (SST) and 10m wind correlations strengthen as the solar radiation varies from zero at night (local time) to a maximum insolation around midday (local time). In addition, there are significant variations in correlation intensities and structures in response to synoptic-timescale forcing. Significant positive correlations between SST and 10m wind errors in the western North Atlantic are associated with variations in low surface pressures, while negative correlations across the Indo-Pacific Warm Pool are associated with light wind conditions on these short timescales.
When we consider the spatial extent of cross-correlations, we find that in the Gulf Stream region positive correlations between wind speed and sub-surface ocean temperatures are generally vertically coherent down to a depth of about 100m, consistent with the mixing depth; however, in the tropical Indian and West Pacific oceans, negative correlations break down just below the surface layer. This is likely due to the presence of surface freshwater layers that form from heavy precipitation on the tropical oceans, manifested by the presence of salinity-stratified barrier layers.

Design of an OSSE to assess the impact of ISRO proposed Microwave Humidity Sounder in a low earth inclined orbit	Indira Rani S, NCMRWF

Megha-Tropiques (MT) was one of the successful Indo-French space missions in the low earth orbit of inclination 20° with continuous coverage over the Tropics. SAPHIR, a sounding instrument with 6 channels near the absorption band of water vapor at 183 GHz, was one of the payloads onboard MT designed to improve the sampling of the diurnal cycle of water vapor and the evolution of convective systems over the Tropics. Major global operational NWP centres have already explored the potential of SAPHIR in clear-sky and all-sky conditions. NWP community is in demand of SAPHIR like channels in the low earth inclined orbit with more repeativity over the Tropics. Indian Space Research Organization (ISRO) is planning an experimental mission for the 3D humidity profiling from the surface to 12 km; as a follow on mission to SAPHIR. The proposed mission, Microsat-2B with an MHS will be launched in a 37° inclined low earth orbit at an altitude of 450 km and operates in the frequency band of 183±16.25 GHz, with a resolution of 2 km in the vertical and 10 km in the horizontal. NCMRWF is developing the assimilation capability of Microsat-2B MHS radiances in its NWP systems through Observing System Simulation Experiments (OSSEs). This paper briefly touches upon the characteristics of different channels of the new instrument compared to SAPHIR channels, design of the OSSE, innovations in the background and analysis fields in the OSSE, and the preliminary impact of the proposed new instruments in the NWP.

Assessment of the impact of adding ocean ensemble capability to the Met Office coupled NWP system	Daniel Lea, Met Office [ONLINE]

The Met Office coupled Numerical Weather Prediction (NWP) system uses weakly coupled data assimilation for the deterministic forecast uses a coupled model at N1280 (~10 km) resolution in the atmosphere and about 1/4 degree resolution in the ocean and sea-ice (extended ORCA025 grid). A coupled ensemble is run with lower N640 (~20 km) atmospheric resolution, and the same ocean and sea-ice resolution as is used in the deterministic system. The atmospheric data assimilation is an ensemble data assimilations (EDA) applying hybrid 4DEnVars to each member but in the ocean, at present, there is no ensemble data assimilation included and each ocean ensemble member is initialised using the deterministic ocean analysis.

To add the ocean ensemble to the NWP system we updated the ocean model, NEMO to include stochastic model perturbations. An EDA approach is used whereby each ensemble member runs its own, 3DVar in this case, ocean data assimilation with perturbed observation values and locations. The system is capable of running hybrid-3DEnVar, whereby the background error covariances used in the data assimilation are a linear combination of the existing modelled error covariance and an ensemble-based error covariance. An ensemble inflation scheme based on the Relaxation to Prior Spread (RTPS) method is added to the ocean/ice ensemble system.

Here we present the results of 3 month trials of the coupled NWP system. To reduce computational cost, the atmosphere is run at lower resolution of N640 (deterministic) and N320 (ensemble) with the ocean resolution still 1/4 degree. We look particularly at the impact on the atmosphere including ensemble diagnostics like the CRPS (Continuous Reliability Probability Score). We also assess the performance of the ocean component and show that the ocean ensemble produces a reliable forecast (as has previously been shown in an ocean-only version of the system).

PARALLEL SESSION 6: Observing and predicting lightning risk over the Indian region
Wednesday 1st March 2023

Relationship Between Convective Storm Properties and Lightning Over the Western Ghat	G. Pandithurai	IITM

X-band radar observations are integrated with lightning location network observations to investigate the relationship between convective storm properties and lightning over the Western Ghats during a monsoon season (June–September 2014). Convective storms (cells) were identified using an objective-tracking method and instantaneous lightning strikes within the radar domain were then linked with observed storms. This spatio-temporal sampling of individual convective cells and lightning has facilitated process-based study of electrified convection over the Ghats for the first time. Storm and lightning occurrences are typically high during monsoon onset and withdrawal months of June and September, respectively. A spatial correspondence between deep-intense storms, lightning, and intense convective cores indicated presence of large hydrometeors in the mixed-phase region of storm supported by strong updrafts and is essential for lightning. The large-scale instability that peaked during afternoon hours was a key factor in the formation of deep-intense storms and lightning. Results show that majority of lightning-producing storms are located on the leeward side as opposed to the windward side. These storms have deeper top-heights, larger areas and vertically integrated liquid, and an enhanced hail probability than those devoid of lightning. Warm season convection in the study area is accompanied by the preponderance of negative Cloud to Ground (−CG) flashes over positive Cloud to Ground (+CG) lightning. Storms with +CG features exhibited much higher (>2 times) vertical airmass flux in the mid-troposphere (6–9 km) than storms without +CG features. Furthermore, for majority of +CG storms, intracloud flash occurrences increased significantly above the freezing level.

Performance and tuning of the lightning scheme in a convective scale model over India	Saji Mohandas	NCMRWF [online]

The regional version of NCMRWF operational Unified Model (NCUM-R) uses the lightning parameterization scheme developed by McCaul scheme which diagnose the lightning potential at a grid location based on the cloud microphysical properties and its distribution. Since it is mainly dependent on the graupel flux and the vertically integrated ice hydrometeor distribution, any change in the cloud microphysical schemes need a thorough validation of the lightning flash rates produced by the model. The details of the performance of the lightning scheme for the previous version of the model and the tuning process for the recent science changes will be presented.

Development of a Dynamical Prediction System for Lightning Forecast over India	Greeshma M Mohan	NCMRWF

With a view to develop an in-house lightning prediction system for the Indian subcontinent, sensitivity study has been carried out by implementing the existing dynamical lightning parameterization (DLP) schemes in Weather Research and Forecasting (WRF) model. The experiments are conducted over Maharashtra state, India with a 4 domain system having resolutions 27, 9, 3, and 1 km and analyzed for a period of 24 h. With the availability of observed lightning data from the lightning detection network (LDN), severe lightning cases have been identified during pre-monsoon season for the period of 2016-2018. The sensitivity experiments are conducted to identify better (i) lightning parameterization scheme and (ii) microphysics scheme. The results from the above experiments show (i) better spatial pattern and frequency distribution in terms of lightning flashes, (ii) maximum reflectivity and its time evolutions are in good agreement with lightning flash, (iii) the number of matching grid boxes due to randomness is higher, and (iv) the results based on Lightning Potential Index are also in agreement and consistent with observation. The lightning parameterization based on cloud top height defined by the radar reflectivity factor threshold of 20 dBZ (DLP2) has performed better than other DLPs. The results highlight that there is fairly good POD of 0.86, 0.82, 0.85, 0.84 and false alarm ratio (FAR) of 0.28, 0.25, 0.29, 0.26 from four different microphysical schemes, WSM6, Thompson, Morrison and WDM6 respectively with DLP2. These high skill scores and high degree of correlation between observations and model simulation give confidence to use this system for real-time operational forecast. This modeling system made operational in April 2019. The skill for 2019 and 2020 pre-monsoon are calculated to address the predictability of operational lightning prediction over India

Explicit lightning forecasting over North Eastern India and preliminary results over PAN India	T Banik	IMD

This work is an attempt to demonstrate the utility of an explicit electrification module coupled with the weather research and forecasting model (WRF) to forecast lightning activity initially over north eastern India followed by PAN India. In the lightning forecast model, both inductive and non-inductive charging scheme of hydrometeors are considered along with polarization of cloud water, and the exchange of charge during collisional mass transfer. This module calculates explicitly the three components of the ambient electric field through a computationally efficient multigrid elliptic solver. A bulk discharge scheme is also included, wherein charge within a volume is reduced whenever the magnitude of the electric field exceeds the local breakdown threshold. Several case studies have been evaluated over the study region. An extensive analysis has been carried out for thunderstorms events on 3 April and additional days over north-eastern India. The simulated flash origin densities (FOD) are evaluated against observed total lightning from the Earth Networks ground based sensors. Together with the electrification module, a lightning assimilation technique has also been employed in EWRF to better represent the observed lightning on the innermost convection-allowing grid (3 km) during the analysis. This study further focuses the sensitivity analysis of EWRF and its validation for the complete pre-monsoon season of 2019. Different statistical score have been calculated for the whole season to assess the model performance over north astern part of India. The further work is going on to scale up the model for PAN India.

Analysis of threshold values of Various thermodynamic indices for thunderstorm prediction over Delhi	Shivinder Singh	IMD

Thunderstorms and associated phenomenon are a major hazard for life and property in India. Every year many lives are lost and other damages occur due to these thunderstorm events. Accurate forecast with sufficient lead time can greatly reduce these losses. Thermodynamic indices are very good tool to assess the instability of the atmosphere which give rise to convective storms. Various thermodynamic indies have been extensively studied and many thresholds are also available, but as thunderstorms are mesoscale phenomena these threshold tends to vary from one location to another. Moreover, all thermodynamic indices don't give equal guidance for different locations and seasons. An attempt has been made to do a comparative analysis of various thermodynamic indices over Delhi using upper air sounding data from 2000-2020 for Delhi obtained from University of Wyoming website(https://weather.uwyo.edu/upperair/sounding.html). Thunderstorm and non-thunderstorm days data was obtained from India Meteorological Department(IMD) for the same period for Delhi. SWEAT, Lifted Index(LI), Showalter Index, K-index Cross Totals, Vertical Totals and Total Totals Index were analyzed in the present study for the months of March, April, May June and July. Distribution of Thunderstorm and non-thunderstorm days were computed for each index for each month. Percentage of thunderstorm days was also computed for various threshold values for each index for each month. K-Index and SWEAT Index showed more percentage of thunderstorm days compared to other indices whereas CAPE was the least efficient among all indices studied. Only K-Index for the month of June had 50 percent Thunderstorm days for values greater than 45.

Severe Convection Products derived from Satellite Imagery	Rory Gray	Met Office

Overshooting tops (OTs) are important meteorological phenomena, their locations indicating regions of intense storm activity. Within or near the convective updrafts of a thunderstorm anvil cloud, and in the vicinity of an OT, small high altitude ice crystals (HAIC) can form. The presence of OTs and HAIC indicate regions of particularly severe convection, which produce thunderstorms and

hazardous weather conditions, including frequent lightning, as well as heavy rainfall, hail storms and high winds at the ground.
New products that use satellite imagery to estimate locations of OTs and HAIC have been developed, which can be used to forecast the onset and presence of severe storms and lightning, as well as to warn the aviation community of potentially serious aviation hazards.
Satellite imagery from the SEVIRI instrument on MSG over the Indian Ocean (soon to be replaced by FCI on MTG) is used to estimate geographical positions of overshooting tops over the Indian region by searching for cold locations within otherwise homogeneous regions deemed likely to contain anvil cloud. An IR module detects OT locations, with a visible reflectance confidence check performed during times of daylight. The OT product shows estimated locations of OTs as well as a quantitative rating of regions likely to contain convective anvil cloud. A numerical estimate of the probability of HAIC presence in the vicinity of the detected OTs is then assigned by applying formulae derived by the NASA Langley Research Center from field campaigns.
A further product to estimate Ice Water Path (IWP) is also being developed. The predicted lightning flash rate at a location depends on the ice water path and the IWP product should prove useful in the evaluation of lightning models.
The methods and product examples, including preliminary comparisons with lightning model forecasts, will be presented.

The seasonal distribution of lightning fraction over the Indian Region	Rakesh Ghosh	IITM

The three years of IITM LLN lightning observation data are used to determine the seasonal and spatial (over different geographical locations) distribution of the ratio of intra-cloud lightning (IC) to cloud-to-ground lightning (CG) in thunderstorms over the Indian region. The ratio is high (8-10) in the northwestern regions and low (0.3-3) in the north-eastern regions. In the Pre-monsoon (March to May), the three-year mean ratio is observed to be high, and during Monsoon (June to September), the ratio goes down over the Indian region. Though CAPE is the regulating factor, little dependency has been found between the ratio of IC to CG lightning and the total flash rate and cold cloud depths. The ratio is observed to be proportional to the total flash rate as 〖 f〗 ^0.61. The cold cloud depth is most prominently linked with the regional and seasonal IC: CG ratio. High CAPE associated with a stronger vertical updraft enhances the cold cloud depth and expands the mixed phase region, which can broaden and uplift the size of the upper positive charge center inside a thunderstorm while the middle negative charge center remains at the same temperature level. Therefore, it enhances the occurrence of IC discharge between the upper positive charge center and the middle negative charge center, increasing the IC: CG ratio of a thunderstorm. The implication of these observed results has the importance of separating CG lightning flash from total and can be used in numerical models in offline and online modes to properly predict CG lightning in hazard mitigation.

Diurnal Cycle of Thunderstorm activity over the Indian region	Pradeep Sharma	IMD

Quantifying the impact of lightning observation representativeness errors using a spatial verification method	Marion Mittermaier	Met Office [online]

Lightning observations are essentially instantaneous point observations with an assigned latitude and longitude. Though lightning can travel 10s of kilometres in the horizontal this is not necessarily reflected in the location information. Lightning flash count forecasts from Numerical Weather Prediction (NWP) forecasts are strongly dependent on the underlying model resolution and generally provide a larger footprint than what is observed.

Gaussian kernel dressing can be used to increase the footprint of highly localised observations to help mitigate against the representativeness mismatch. Here "dressed" lightning flash count fields are used in a novel way with the spatial Coverage-Distance-Intensity (CDI) verification method to attempt to quantify the spatial representativeness mismatch.
Results show that when accounting for a representativeness mismatch, the median coverage component changes by 38%, yielding a more symmetrical and centred distribution of the forecast coverage. This reduces the risk of concluding that there is a systematic over-forecast bias in the model areal coverage. Use of a smoothed binary field also leads to a similar change in the intensity component, highlighting the influence of observation uncertainty on intensity biases. This work shows that the coverage component of the CDI method could potentially be used to help provide greater confidence in the interpretation of verification results.

PLENARY 6: Observing and predicting lightning risk over the Indian region

Tuesday 28th February 2023

Evaluation of lightning forecasts from the High-Resolution Rapid Refresh (HRRR) modelling system with ground-based lightning data	B R R Hari Prasad Kottu, NCMRWF

The High-Resolution Rapid Refresh (HRRR) model forecasting system can simulate the location and timing of the convective systems well due to the assimilation of available observations more frequently. So It can be used for the nowcasting of various weather events such as lightning, thunderstorms, etc. In the present study, lightning forecasts from the HRRR modelling system are evaluated during the pre-monsoon season of 2022. Ground-based lightning data is used to evaluate the performance of the HRRR lightning forecasts. Two sets of experiments have been done: (1) assimilation with prepbufr data alone and (2) assimilation of radar and lightning data along with prepbufr data. The verification metrics using a 2x2 contingency table such as Probability of Detection (POD), False Alarm Ratio (FAR), and Threat Scores (TS) are calculated. Fractions skill score (FSS) were also calculated within circular neighbourhoods with radial distances from 3 to 240 km. With such high skill scores and a high degree of correlation between the ground-based lightning observations and HRRR model simulations, we are confident in using the system for real-time operational forecasting over India.

Exploring relationships between the CASIM microphysics and forecast lightning flash rates	Jonathan Wilkinson, Met Office

Lightning is a high-impact meteorological event and can be difficult to forecast accurately. Since 2012, the Met Office has been running a lightning parametrization based on upward fluxes of graupel and total column ice. This has been used in the Met Office regional atmosphere RA1T and RA2T configurations over India. During the recent RAL3 development cycle, the older Wilson/Ballard microphysics was replaced with the complex double-moment Cloud-AeroSol Interacting Microphysics (CASIM) scheme. By changing the structure of the cloud microphysics, the lightning forecasts have themselves seen significant changes and a retuning has been performed as part of the RAL3 configuration. However, little work has been done to understand how the cloud microphysics changes relate to the lightning flash rates. In this presentation, we will discuss progress made to date to understand the relationships between the microphysics and the lightning flash rates for a number of case studies over India, the UK and elsewhere.

Thunderstorm and Lightning warning system over Jharkhand, India	Preeti Gunwani, IMD

PARALLEL SESSION 7: Improving predictions through machine learning and data sciences
Wednesday 1st March 2023

Use of Machine Learning/AI in weather and climate prediction for India - Opportunities and Preliminary Research	Sean Milton	Met Office

As part of a collaboration with the Foreign, Commonwealth and Development Office (FCDO) the Met Office are undertaking a short 5 month project (Nov 22- Mar 23) to scope and explore opportunities for the use of Machine Learning/AI techniques to improve weather and climate predictions and deliver improved impact based forecasting along the science to service value chain for South Asian Monsoon extreme weather events. The project will deliver a scoping report and some preliminary research to explore hybrid ML-physical modelling approaches to improve weather and climate predictions. This paper will present results from these two aspects and allow a key opportunity for engagement with Indian Partners who are also actively engaged in scoping ML techniques (Singh et. al., 2022) and with the wider UK/India WCSSP India Partnership around future planned activities in Machine Learning, AI and Data Science.

Reference:

Manmeet Singh et.al, 2022: Artificial intelligence and machine learning in earth system sciences with special reference to climate science and meteorology in South Asia, CURRENT SCIENCE, VOL. 122, NO. 9, 10 MAY 2022.

A Machine Learning Based Generation of Dynamic Blending Weights for Rainfall Analysis Product	Preveen Kumar D	NCMRWF

A high temporal and spatial resolution rainfall analysis product is essential in Numerical Weather Prediction (NWP), hydrological and earth system modelling. The analysis product is usually generated by merging (or blending) bias-corrected multi-sensor satellite estimates, point observations recorded by station gauge networks and Doppler Weather Radar (DWR) data, according to their weights. These blending weights are spatially and temporally dynamic and thus have to be generated daily for accurate estimation of precipitation. In this study, we looked into the effectiveness of machine learning techniques for producing weights for blending high resolution rainfall data. The weights were created using the India Meteorological Department (IMD) gridded rainfall data. Daily data of 25 years (1992–2016) were used for training, validation, and testing during the study period. A Convolutional Neural Network (CNN) and Long Short Term Memory (LSTM) based approaches were evaluated. The results showing the comparison between the general algorithm of the distance-based weighting scheme and machine learning method will be shown.

A Novel Approach for Recognizing Remote Sensing Images for Cyclonic Storms Using Deep Learning Algorithms	Manikyala Rao Tankala	IMD [online]

The field of Remote Sensing (RS) technology has advanced quickly in recent years. A vast number of satellite cyclonic images across the surface of the globe have been obtained with various levels of spatial, spectral, and temporal resolution. Thanks to the development of monitoring capabilities and the rise in the number of remote sensing platforms, in many applications, including natural disaster detection, agricultural survey, urban planning, resource monitoring, weather forecasting, land-cover/land-use classification, and geographic space object detection retrieval, these images serve as a valuable source of information that can be used to inform decisions. Analyzing these images is therefore crucial from a social and economic standpoint. Remote sensing image classification is a technique that divides RS scenes into groups based on the cloud distribution they contain. The RS literature contains numerous articles that address this issue, especially Convolutional Neural Network (CNN) models, which have been used in recent state-of-the-art efforts to identify RS situations and learn rich feature representations of them. The majority of this

art work incorporates elements that fully capture the RS scene with convective cloud distribution. However, frequently, only one component of that image can be used to determine which class it belongs to, while the remaining components are either useless or belong to a different class. As a result, necessary cyclonic cloud distribution elements are classified as cyclonic storms, while the remainder are classified as non-cyclonic storms.

Training a deep neural network (DNN) to recognise satellite cyclone images having noise and blur in the infrared and visible spectrum typically relies on supervised learning, which requires input–target pairs of noisy images and corresponding blurred images. Although previous approaches have shown promising results in the recognition of satellite cyclone images, it is difficult to localise cyclone storm cloud distribution in images, which requires additional training on networks. In this paper, we propose a self-supervised learning approach to train a DNN with real-time visible and infrared spectrum images alone. As a means of self-supervision, the proposed approach recognises cyclone cloud distribution in images having convective activity as well as wall clouds in the electromagnetic spectrum. To regularise the DNN based localization, thicker cloud distribution images having eye as a characteristic are used as image priors during the self-supervised training process in our approach. For efficient self-supervised learning, we adopt a two-stage training strategy with offline pre-training on cyclonic images of the Bay of Bengal and Arabian Sea and test the localization on real-time images of INSAT-3B. The proposed approach is thoroughly evaluated with satellite cyclone images of Sitrangi,Mandous,Nisarga, Bureive, Gulaab, Yaas, BoB, Tauktae, etc.. Performance metrics are evaluated using a Confusion Matrix and graphical plots. The experimental results also show that our proposed method outcasts the remaining models in terms of performance of supervised learning models as well as localisation learning models at test time. Further, higher Validation accuracy is achieved on a real-time images.

PARALLEL SESSION 8: Coupled model development, evaluation and inter-comparisons
Thursday 2nd March 2023

Intraseasonal variability of Summer Monsoon Rainfall in Observations and CMIP6 models simulation	Pradhan Parth Sarthi	U. South Bihar

The intraseasonal variability of Summer Monsoon Rainfall (SMR) provokes meteorological drought and flood conditions in India. Because of this importance, the intraseasonal variability of SMR over the Eastern Gangetic Plain of India comprising the meteorological subdivisions, namely West Bengal (WB), Jharkhand (JH), Bihar (BR), East Uttar Pradesh (EUP), and West Uttar Pradesh (WUP), respectively, is analyzed in terms of large-scale precipitation (LSP) and convective precipitation (CP) using the data of zonal, meridional (u and v components) wind, and relative humidity (rh) at the spatial resolution of 0.25° × 0.25° (1980–2019) of the European Centre for Medium-Range Weather Forecasts (ECMWF), UK. The daily climatological values of CP (LSP) are relatively higher (lower) in each meteorological subdivision. Between the pressure levels of 1000 to 700 hPa, the change in the zonal wind, i.e., easterly to westerly and vice versa, and occurrence of a large amount of rh (>80%) may be possibly initiated moist convective activity for more precipitating out CP over the Gangetic West Bengal, Jharkhand, and Bihar in comparison to East and West Uttar Pradesh.
In CMIP6 simulations, the performance of BCC-CSM2-MR and BCC-ESM1 of the Beijing Climate Center, China, and MPI-ESM1-2-HR and MPI-ESM1-2-LR of Max Planck Institute (MPI) Germany, are evaluated under historical experiment (during 1979 to 2014) of CMIP6. The simulated wind circulation, and relative humidity are evaluated and validated against the respective observed/reanalysed data on the seasonal and sub-seasonal scales to find the possible linkage with the SMR variability. The evaluations show that the CMIP6 models of BCC-CSM2-MR performs well in reproducing relative humidity over the Arabian Sea and the Bay of Bengal. The models BCC-CSM2-MR and BCC-ESM1 perform well in simulating JJAS rainfall in comparison to observed rainfall of India Meteorological Department (IMD).

Sub seasonal Drought Assessment in NCMRWF Multi-Week Extended Range Prediction System	Kondapalli Niranjan Kumar	NCMRWF

Drought is a complicated phenomenon, and the least understood of all "weather and climate extremes". Drought can be classified into different categories such as meteorological, agricultural, hydrological, and socio-economic droughts. In this study, we particularly focused on meteorological droughts which occur in long gaps in normal rainfall. The water shortages caused by meteorological droughts impact life even beyond health and hygiene. The countries like India where the livelihood of 60% of the population depends on agriculture, drought is one of the most feared natural calamities as it impacts food production, economy, and morale of millions of farmers in the country. More importantly, recent studies stressed on flash droughts are characterized by rapid onset and intensification, unfolding on sub-seasonal to seasonal(S2S) time scales posing a new challenge for the S2S model prediction capability. Hence, we explored the performance of an multi-week extended range prediction system (NERP) based on the Unified global coupled modelling system that has been implemented at the National Centre for Medium Range Weather Forecasting (NCMRWF) in characterizing the droughts on sub-seasonal time scales. For identifying the droughts, we have used Standardized Precipitation Index (SPI) which considers only precipitation. Our focus is primarily on the Southwest monsoon season (June–September) which is the primary rainy season in India and contributes 70–90% of the annual mean rainfall. We also laid a particular emphasis on the flash droughts based on the short time scale(1-month) and high-frequency data(weekly) based on the anomalous decrease in index values in a short time (4 weeks). Therefore, this study has important implications for drought assessment, monitoring, and mitigation.

Coupled NWP using the ORCA12 ocean model	Tim Graham	Met Office

In Spring 2022 the Met Office implemented operational coupled NWP with atmosphere resolution of 10km for deterministic and 20km for the ensemble, both coupled to the NEMO ocean and CICE sea-ice models on the ORCA025 (1/4º) grid. A likely future development will be an upgrade of the ocean resolution to ORCA12 (1/12º). In this talk we will show results from a year long hindcast of a N1280-ORCA12 model compared to N1280-ORCA025. Analysis in this talk will include assessment of the simulation of sea surface temperature in both models; assessment of simulated currents using nearest neighbourhood methods and analysis of SSH variability using complex EOFs and comparing to regular EOFs.

Development of an India Water Model (IWM) for water management and forecasting applications	Manabendra Saharia	IIT Delhi

A land data assimilation system plays a pivotal role in effective water resources management by providing reliable estimates of various land surface states and fluxes including water balance components. An India Water Model (IWM) has been setup that aims to provide spatially consistent, high resolution and reliable estimates of land surface states, water balance and energy fluxes over the Indian mainland. The IWM is built on NASA's Land Information System Framework (LISF), which is an open-source framework that enables a multi-model, multi-data approach to terrestrial modeling. In this study, we evaluated the water balance components simulated using IWM while driven by three reanalysis meteorological forcing datasets: Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2), and Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) and ECMWF's ERA5. The multi-site autocalibration is performed on multiple catchments to further improve the performance of IWM. We have used Kling-Gupta Efficiency (KGE) and its components to evaluate the major components of the terrestrial water balance: surface runoff, soil moisture, terrestrial water storage anomalies, evapotranspiration, and monthly mean streamflow, against a combination of satellite and in-situ observation datasets. We also assessed the uncertainty and bias due to spatio-temporal heterogeneity in the forcing precipitation by validating against gauge-based gridded precipitation provided by Indian Meteorological Department (IMD). Overall, considering nationwide median KGE scores, CHIRPS showed the highest performance for surface runoff and streamflow. However, MERRA-2 performed the highest in soil moisture simulation whereas ERA5 showed best results in total evapotranspiration.

Simulations of monsoon depressions over the Bay of Bengal using coupled and atmospheric regional models	Sandeep Pattanaik	IIT Bhubaneswar

The present study is aimed to investigate the rainfall characteristics of Monsoon Deep Depressions (MDD) originating over the Bay of Bengal (BoB) basin using a coupled ocean-atmospheric model (COAWST) and a stand-alone atmospheric (WRF) model with a lead time of up to 72h. It is found that though the tracks of the four MDDs considered in the study have been reasonably simulated, the intensity was overestimated in both sets of simulations compared to India Meteorological Department (IMD) best estimates. Upon decomposition of the contributors to the rainrate for the composite of the storms in the deep depression (DD) phase, it was found that the moisture sources/sinks play a more important role than the cloud sources/sinks in modulating the rainfall processes. Further analysis of the moisture sources/sinks showed that the horizontal and vertical advection are the major drivers in modulating the contribution of the moisture sources/sinks. The validation of rainfall using CMORPH datasets suggested that the coupled simulations had a higher skill in rainfall prediction. Furthermore, the composite of different components of moisture sources/sinks (especially vertical advection) was found to be more realistically simulated in COAWST compared to CNTL upon validation with MERRA datasets. Analysis of the composite energetics showed that scarcity of bulk kinetic energy in the later hours of the DD phase in COAWST led to the dissipation of the storm core, which led to better prediction of rainfall. On the other hand, a re-intensification of the storm core by means of condensational heating led to an overestimation of rainfall in WRF, which finally resulted in lower skill in rainfall prediction. In spite of the stand-alone atmospheric model capturing the horizontal moisture incursion in the lower levels significantly, the better representation of the vertical structure enabled the coupled model to capture the precipitation features more realistically, increasing skill in rainfall prediction.

Monsoon Mission Climate Forecast System 2: Preliminary Results	Suryachandra Rao	IITM

Some preliminary results from Monsoon Mission Coupled Forecast System version 2 (MMCFSv2) model, which substantially upgrades the present operational MMCFSv1 (version 1) at the India Meteorology Department, will be presented. We evaluate MMCFSv2 based on the latest 25 years (1998-2022) of retrospective coupled hindcast simulations of the Indian Summer Monsoon with April initial conditions from Coupled Forecast System Reanalysis. MMCFSv2 simulates the tropical wind, rainfall, and temperature structure reasonably well. MMCFSv2 captures surface winds well and reduces precipitation biases over land, except in India and North America. The dry bias over these regions remained like MMCFSv1. MMCFSv2 captures significant features of the Indian monsoon, including the intensity and location of the maximum precipitation centres and the large-scale monsoon circulations. MMCFSv2 improves the phase skill (anomaly correlation coefficient) of the interannual variation of ISMR by 30% and enhances the amplitude skill (Normalized Root Mean Square Error) by 20%. MMCFSv2 shows improved teleconnections of ISMR with the equatorial Indian and Pacific oceans. This 25-year hindcast dataset will serve as the baseline for future sensitivity studies of MMCFSv2.

Regional downscaling of dynamic sea level of the Indian Ocean based on CMIP6 models	Abhisek Chatterjee	INCOIS

Sea level change is one of the most influential and critical manifestations of global climate change. Rising mean sea level enhances the risks of flooding, coastal erosions, contamination of resources, loss of habitat and much more. The Indian Ocean, with a densely populated coastline, is prone to many such climate disasters. The design of policies to mitigate the effects of the rising sea level under the global warming scenario requires a deep understanding of the dynamics of the factors driving the sea-level change.

Phase six of the Coupled Model Intercomparison Project (CMIP6) provides a large ensemble of standardised model output covering the historical span of 1850-2014 and projected changes till 2100 under different emission scenarios. In this study, we analyse the dynamic sea level (DSL) and surface winds from 27 models and its future projections under mid (SSP2-4.5) and high (SSP5-8.5) emission future scenarios over the Indian Ocean. We look at the representation of simulated large-scale features, climate modes and remote influences through inter-basin transports by these models, documented the common caveats and the inter-model spread in the ensemble across the different parts of the Indian Ocean basin. Most models reproduce the observed mean state of the dynamic sea level realistically; however, consistent positive bias is evident across the latitudinal range of the Indian Ocean. The equatorward shift of the southern hemisphere wind field results in the strongest sea level bias in the Antarctic Circumpolar Current fronts. Moreover, this equatorward bias of the trade winds causes anomalous equatorial easterlies resulting in sea level bias towards tropical Indian Ocean zonal mode.

We employ a suite of objective and subjective selection rationale to create a subset of the best-performing models based on their fidelity in historical simulation and assess the future projection over the Indian ocean. Interestingly, while high-resolution models compare better in simulating sea level variability, this improved simulated variability not necessarily translates into an improvement in simulation for the mean state. Interestingly the best-performing subset shows a weaker sea level rise compared to the ensemble mean. In summary, this study reiterates the importance of reducing the spread of the projected sea level with a minimum risk of mal-adaptation for proper policymaking.

Citation: Sajidh, C.K. and Chatterjee, A. Indian Ocean dynamic sea level, its variability and projections in CMIP6 models. Clim Dyn (2023). https://doi.org/10.1007/s00382-023-06676-z

The Indo-Pacific PEG and common Indian Ocean biases	Hannah Ellis	Met Office [online]

Analyses carried out at the Bureau of Meteorology, European Centre for Medium-Range Weather Forecasts and the Met Office in 2019 revealed very similar biases in the Indian Ocean in initialised coupled forecasts. This motivated the formation of the Indo-Pacific Prioritised Evaluation Group (PEG) between the three centres along with other forecasting centres within the Unified Model Partnership to understand and improve common biases in the Indo-Pacific region and associated teleconnections. The prominent cold sea surface temperature (SST) bias seen in the Eastern Indian Ocean is of particular interest, given the importance of this region for global climate variability and associated teleconnections. A number of potential sources of error are currently being investigated. One hypothesis being explored is the role of the Indonesian Throughflow on the eastern cold SST bias and if the bathymetry or resolution of the model impacts the throughflow transport, in turn affecting the Indian Ocean SSTs.

Representation of the surface roughness at high wind speeds in atmospheric and wave models	John Edwards	Met Office [online]

Tropical cyclones are a significant natural hazard in the Indian region. The low central pressure of a landfalling tropical cyclone may generate a storm surge along the coast, while high wind speeds may cause extensive damage. The simulated wind speeds in a tropical cyclone are very sensitive to the representation of sea-surface roughness, however this is not well characterized at high wind speeds. Although observations suggest that it attains a maximum value at speeds of about 30 ms-1 and decreases at yet higher wind speeds, standard parametrizations in atmospheric and wave models, developed for lower wind speeds, do not exhibit this behaviour. A heuristic modification designed to represent this effect is currently used in the operational global atmosphere-ocean forecasting system at the Met Office.

Newer theoretical developments indicate how the effect may be represented in the parametrized source terms in a wave model. We compare the roughness lengths derived using these revised source terms with those obtained from the uncoupled parametrization and explore their impact on the simulation of an intense tropical cyclone in the Bay of Bengal.

PLENARY 5: Coupled model development, evaluation, and inter-comparisons

Tuesday 28th February 2023

NCMRWF Extended Range Prediction System	Ankur Gupta, NCMRWF

With the developments in the parameterization of atmospheric and oceanic processes and air-sea interactions in dynamic models, the prediction at the sub-seasonal scale has become a reality. The prediction of rainfall at these timescales is very useful for the water, agricultural, and energy sectors in India. Recently, an extended range prediction (NERP) system has been implemented at National Center for Medium-Range Weather Forecasting (NCMRWF, Gupta et al., 2019). The system is based on a coupled model with UM as atmospheric, JULES as land surface, NEMO as ocean, and CICE as seaice model and includes the GC2 science configuration of Williams et al., 2015. Gupta et al., 2019b show that the UM-based coupled model is able to capture the large-scale circulation, rainfall patterns, sea surface temperatures, ocean currents, and seaice reasonably well at up to 15-days of leadtimes. Since 2018, the system is used for providing inputs to the Indian Meteorological Department (IMD) for the issuance of multi-week forecasts every Thursday. However, the skill of the model for forecasting monsoonal rainfall at sub-seasonal scales is not known. Recently, an analysis of the NCMRWF extended range prediction system (NERP) is done to evaluate both the deterministic and probabilistic skill (Gera et al., 2022). The results show that the NERP has useful skill for week-2 forecasts and that model captures the onset of monsoon and interannual variations of northward propagation of the rainfall reasonably well several weeks in advance. Probabilistic scores of reliability, Receiver Operating Characteristic (ROC), and fair continuous ranked probability score (FCRPS) show that the model exhibits good skill over most regions till week-2 and moderate skill in weeks 3–4 over other regions.

Evaluation and comparison of the sub-seasonal prediction skill of Indian summer monsoon in IITM CFSv2 and UKMO GloSea5	Susmitha Joseph, IITM

The current study compares the extended range prediction skill of the Indian Institute of Tropical Meteorology (IITM) generated real-time forecast with that of the UK Met Office (UKMO) forecast during the boreal summer monsoon season. It is found that both models suffer from biases in the climatological mean state of the monsoon. IITM forecast possesses a skill comparable to UKMO coupled seasonal forecast as compared to the observation in the first two weeks leads over most of the meteorological subdivisions during the monsoon months of June to September. However, at longer leads, the UKMO model outperforms the IITM model, which could be credited to its enhanced skill in predicting the monsoon intraseasonal oscillations and the better representation of monsoon variability at the intraseasonal time scale.

Advances in weather forecasting enabled by Regional Environmental Prediction research and its implementation at NCMRWF	Ségolène Berthou, Met Office Akhilesh Kumar Mishra NCMRWF

In partnership with other UK institutions and NCMRWF, the UK Met Office has developed a regional environmental prediction system at km scale, over two domains: the Northwest European shelf and the Indian region. This provides a flexible research capability with which to study the interactions between atmosphere, land, river, ocean, wave and biogeochemistry processes resolved at km-scale, and the effect of environmental feedbacks on the evolution and impacts of multi-hazard weather events. The coupled system incorporates models of the atmosphere (Met Office Unified Model), land surface with river routing (JULES), shelf-sea ocean (NEMO), ocean surface waves (WAVEWATCH III) and biogeochemistry (ERSEM) coupled together using OASIS3-MCT libraries and the FabM coupler. This research framework has enabled to uncover interesting scientific results and to improve to both atmospheric and marine weather prediction. Recent developments have further enabled to run the system in ensemble forecast mode and in climate mode. We present advances allowed by this system, such as:

- changes to tropical cyclone prediction from atmosphere-ocean coupling mostly, coupled system enabling a more rigorous treatment of the near-surface energy budget
- Integrated hydrology over the UK and future steps over India
- benefits of ocean/wave coupled system for marine forecasting
- Improvements of summer temperature forecasts over the UK by using SST prediction from the marine prediction system
- improvements to winter storm wind forecasting when coupling the atmosphere with the wave models

High-resolution regional forecast products are very useful for many sectorial applications such as water (hydrological applications), energy, agriculture & disaster managements. These regional models get their boundary forcing from coarser resolution global models and are computationally less expensive compared to their global counterparts. NCMRWF has an operational regional atmospheric forecast system (NCUM-R) as part of seamless forecasting system. This model (NCUM-R) is running at 4 Km horizontal resolution over Indian domain and recently upgraded to latest version (version 4) of the regional atmospheric forecast system. India has more than 7500 km long coastlines, and most of the weather events & processes are influenced by surrounding oceans. Air-sea interaction over the oceans plays vital role in formation and movement of weather systems such as thunderstorms, low pressure systems (LPS), monsoon depressions and tropical cyclones. Most of these ocean-atmosphere coupled weather phenomena originating over oceans are impacting coastal states and Indian mainland have their origin over ocean. Kilometre scale modelling and forecasting of such events require a coupled prediction system with atmosphere, ocean, waves & land surface components. Under the MoES-United Kingdom Met. Office (UKMO) collaboration NCMRWF is working closely with UKMO towards testing and setting up a UM based regionally coupled environmental prediction system. We have successfully installed regional coupled suite with UM version 12.1. An attempt is underway to update this system with latest UM , NEMO version 4.04 and Wavewatch III Vn 7.12. Results from initial test runs and planned experiments would be presented during the WCSSP Annual Workshop.

PARALLEL SESSION 9: Predictability, post-processing and verification of high-impact weather

Thursday 2nd March 2023

Observed Changes in Summer Thermal Discomfort over Indian region during 1990-2020	Pravat R Naskar	IMD
An empirical heatwave prediction and monitoring system for operational applications	Lekshmi S	IMD
Heatwaves are periods of abnormally high temperatures more than the normal maximum temperatures. Over the Indian region, intraseasonal oscillations (ISOs) are one of the dominant sources of ordinary and extreme weather conditions. Extratropical Rossby waves intrude over the Indian region and significantly influence the weather features. During the dry summer season, several studies have identified the drivers of heatwaves based on different aspects such as the synoptic scale systems, regional factors, and large-scale teleconnection patterns. Mid-latitudinal heatwaves are identified as the extreme phase of Rossby Wave mode amplification. However, over the Indian region, studies do not explicitly point out the existence of temperature ISO during the season. It is also not known whether heatwaves can be explained as an amplification of such subseasonal modes. In this study, the dominant pair of intrinsic ISO temperature modes are obtained by the empirical orthogonal function analysis of detrended surface temperature. Both modes 1 and 2, which are driven by the mid-latitudinal Rossby waves, follow the subtropical westerly jet waveguide pathway and Europe-Middle East-Indian Ocean pathway, respectively, to propagate towards the Indian region.		
Assessment of temperature forecast from NWP models over Indian cities and its real-time bias correction	M. T. Bushair	IMD
A reliable and accurate air temperature forecast during winter and summer is very much necessary to prepare for and respond to thermal disasters. The numerical weather prediction (NWP) model is commonly used to forecast air temperature using dynamic mechanisms. Most of the time, the temperature forecast over a specific location from different models varies among themselves and also from the observations. This happens mainly due the differences in their assimilation process, formulation, horizontal-vertical resolutions and the parameterization schemes representing the small-scale processes in that model. Thus, due to the errors and biases in the models the direct model output for temperature is not very useful in many occasions. The objective of bias correction is to minimize the systematic error in the direct model output.		
To study the impact of change in schemes for generating model perturbations on the NEPS-G forecast	Gauri Shanker	NCMRWF
National Centre for Medium Range Weather Forecasting (NCMRWF), India runs a global ensemble prediction system (NEPS-G) of 12 km horizontal resolution. It uses Ensemble Transform Kalman Filter (ETKF) method to generate initial condition perturbations for 11 ensemble members. NEPS-G runs twice a day (00 and 12 UTC) and the forecast produced by it at 00 UTC is a combination of 11 ensemble members from the current day 00 UTC and 11 members from the previous day 12 UTC. That way NEPS-G has 23 ensemble members (22 perturbed +1 control). The model uncertainties are taken care of by the Stochastic Kinetic Energy Backscatter (SKEB) and Random parameters (RP)/Stochastic Perturbation of [Physics] Tendencies (SPT) schemes. This article focuses on understanding the role of model physics perturbations on the spread of important atmospheric variables (Temperature at 850 hPa, zonal and meridional wind at 200 and 850 hPa) during the South Asian summer monsoon period for the year 2021 (JJAS 2021) over tropics. Two experiments, one with RP scheme and the other with SPT scheme, have been carried out as part of the first		

investigation to better understand the role of model physics perturbation. The same initial condition has been used for all ensemble members to study the effects of only these physics perturbation schemes. Preliminary results show that the SPT scheme has a positive impact on ensemble spread as well as Continuous ranked probability score (CRPS) for both Temperature and wind over a 7-day forecast lead time. For wind, there was not much change in root mean square error (RMSE) of the ensemble mean but the ensemble spread was found to be significantly large over the tropics for SPT scheme than for the RP scheme. Model evaluations using both the initial condition and model physics perturbations have also been performed in the later part of this study.

Meteorological aspects of floods in relation to heavy rainfall over Odisha	H.R. Biswas Uma S Das	IMD

Floods do have multiple aspects for a state like Odisha, situated on western flank of Bay of Bengal and is largely affected by rain producing low pressure systems, whose genesis mostly happens during the Southwest monsoon season (June-September) and remains the major cause of both flash floods and riverine floods within ten river sub catchments in the state. These flash and riverine floods mostly occurs during major rain producing months (61% rainfall of Jun to Sep) July and August and leads to disruption of people’s livelihoods, casualty, infrastructure destruction and interruption of socio-economic activities. In this paper we deal with the meteorological aspects that is from the prospective of a precipitation event, which need to be adequately understood in order to understand the occurrence and development of floods. This holds the more as different meteorological environments and accompanying mechanisms can result in different types of heavy precipitation and so in different flood responses. To characterise the meteorological aspects of floods, categorisations and the ingredients of the storm systems are presented based on reanalysis data from ERA-5 and on the basis of impact of flood using openly available flood exposure, vulnerability, and near real time flood data. The sequence of these aspects reads as a logical succession of the distinct topics of the meteorological aspects of a heavy precipitation event. Since floods commonly have a profound impact on environment and society, the understanding of the meteorological aspects is a first and necessary step in a challenge of dealing with floods. The ultimate goal of this step is to diminish the harmful consequences of floods as adequately as possible.

PQPF for Monsoon 2020 and 2021 using EnsembleBMA and EnsembleMOS Methods	Abhijith V	NCMRWF

The introduction of probabilistic weather forecasting using the Ensemble forecasting systems is effective in resolving the uncertainty associated with weather forecasting to a greater extent. But the raw ensemble weather forecasts are generally hard to rely upon when comparing with the observations, which results from insufficient model resolution, less-than-optimal initial conditions, suboptimal treatment of model uncertainty and sampling errors. Statistical post processing is inevitable for realizing full potential of ensembles by elimination of biases and reconstruction of proper ensemble spread. Bayesian model averaging (BMA) developed by (Raftery et al, 2005) is a relatively newer method for statistical post-processing of probabilistic forecasts to create predictive probability density functions (pdfs) for weather quantities. The BMA predictive probability density function (PDF) of any quantity of interest is a weighted average of PDFs centered on individual bias-corrected forecasts, where the weights are equal to the models' posterior probabilities and reflect the models’ relative contributions to predictive skill over the training period.
The current study attempts to postprocess the maximum temperature (TMAX) forecasts from two different ensemble models viz. The NCMRWF Ensemble Prediction System (NEPS) running 23 ensemble members at NCMRWF and Global Ensemble Forecast System (GEFS) of IITM run 21 ensemble members for medium range weather forecasting both high resolution (12km) ensemble models. This study evaluates the BMA postprocessing of TMAX from the NEPS and GEFS over the North Indian plains during summer months (March-May) 2019. This area witnesses frequent heatwave conditions during the summer season. We demonstrate an improvement in the

probabilistic forecast of TMAX using BMA. The results reveal that postprocessing effectively reduces (i) the cold bias that is typically observed over the Himalayan region and (ii) the warm bias that is typically observed over the plains. The quantitative verification of post-processed temperature utilizing over CRPS revealed a more than 50% improvement in the region's scores over the summer season. The brier Scores also shown marginal improvement during the period.

Evaluation of Multi-source Ensemble Rainfall Analysis Product over the Indian Monsoon Region	Amar Jyothi Kasimahanthi	NCMRWF

An approach to blend satellite-rainfall datasets over India that could be appropriate for operational use is presented in this study. Here, precipitation estimates from the Global Precipitation Measurement (GPM), Global Satellite Mapping of Precipitation (GSMaP), Indian National Satellite (INSAT) were blended with station-based rain gauge data and DWR rainfall estimates over India to generate a nation-wide rainfall analysis product called Multi-source Ensemble Rainfall Analysis (MERA). MERA product is generated hourly using a Short Term Ensemble Prediction System (STEPS) based method. This product was verified against point gauge observations and the NCMRWF-IMD merged rainfall data product. There is no single source of rainfall data that meets the requirement for real-time applications in terms of coverage, resolution, accuracy, and data latency. MERA provides a solution to these issues. MERA was evaluated both spatially and temporally for extreme events during the Indian summer monsoon 2022. MERA-S (Satellite only) and MERA-SR (Satellite and Radar) products were generated and compared with the standard 25 km NCMRWF-IMD merged data. MERA-SR is able to capture better spatial and temporal variations in rainfall as compared to satellite only version of MERA. A detailed evaluation will be presented.

Indian meteorological ensemble dataset: a gridded ensemble precipitation dataset for the Indian region	Anagha P	IIT Delhi

In numerous applications, grid-based meteorological estimates are crucial. Most available precipitation datasets in India are deterministic and limited in their ability to reflect data's inherent uncertainty. Existing gridded datasets for India were generated using a similar procedure, which included a multi-stage quality check followed by interpolation techniques such as Shepard's and probabilistic interpolation. This study generates an ensemble precipitation product for the Indian region that explicitly accounts for topographical complexity as well as uncertainties in precipitation estimates utilizing a large network of precipitation gauge stations over India with a varying number of stations per year. IMED (Indian Meteorological Ensemble Dataset) generates a daily ensemble precipitation product for the chosen grid utilizing gauge station readings as input, as well as spatial variables like latitude, longitude, elevation, and slope for the period of 30 years from 1991 to 2020. With a resolution of 0.25 and 0.1 degrees, thirty unique ensemble members are generated daily. Gridded precipitation data from IMD (Indian Meteorological Department) and CHIRPS are compared with the mean and median of the created ensemble members. Metrics like mean absolute error, root mean square error, Pearson correlation, etc. are generated to verify the results. IMED and station precipitation data have a correlation coefficient of 0.972, which is higher than the correlation coefficient between IMD and station precipitation data. With the help of this study, forecasters will be able to portray rain more accurately across the Indian subcontinent. Estimate of uncertainty, when included as an integral component of generated datasets, assists in better comprehending and describing the effects of forcing uncertainties.

A case study of exceptionally heavy rainfall event over Uttarakhand, India on 18th October 2021 and its forecasting	Rohit T Vikram Singh	IMD

Assessment of Extreme weather forecasts	Mike Sharpe	Met Office [online]

Extreme weather is assessed using a new verification system, configured to analyse site-specific temperature and 24-hour rainfall forecasts at sites across India against the climatology specific to each observing site. Forecasts are assessed for a variety of extreme events (some of which are expressed as ‘the most extreme event that is likely to occur at a site every n-years’ where, typically n=1, 3 or 5) using the threshold weighted Continuous Ranked Probability Score to generate performance statistics for extreme events at each site. The aim of this work is to investigate how well the current Met Office post-processed numerical model predicts extreme events at observation sites across India, with the possibility of extending to Indian NWP models in a subsequent phase.

PLENARY 11: Predictability, post-processing and verification of high-impact weather

Thursday 2nd March 2023

Potential Economic Value of probabilistic forecast from NCMRWF global ensemble prediction system	Abhijit Sarkar, NCMRWF

A weather forecast is only useful if it can help the users in decision making. One way of determining the difference in value between two forecasts is to compare Potential Economic Values (PEV). Due to the inevitable errors in prescribing initial condition and formulating the model the forecast from a numerical weather prediction model has uncertainty. The uncertainty information associated with the forecast provided by an ensemble prediction system (EPS) can be very useful in the decision-making processes.

NCMRWF Global Ensemble Prediction System (NEPS-G) has 23 ensemble members (1 control +22 perturbed) and about 12 km horizontal resolution. The initial condition perturbation is generated by Ensemble Transform Kalman Filter (ETKF) method. Stochastic Kinetic Energy Back Scattering (SKEB) and Stochastic Perturbations of [Physics] Tendencies (SPT) schemes account for the uncertainty in the representation of model physics. The operational deterministic model forecast is used as the control member.

The forecast from NEPS-G has been used in the present study to investigate the PEV of the probabilistic forecasting of maximum surface temperature (Tmax), temperature at 850hpa (T850) and precipitation with respect to that of the deterministic forecast during the period April-June 2019 over northern India. Ensemble and control forecasts of day1 to day7 have been considered for the present study. Impact of ensemble size on ROC area skill score (ASS) and PEV has also been investigated for extremely hot weather condition during a summer month over Indian region.

Exploring the use of feature-based verification techniques on ensemble forecasts of tropical cyclone rainfall	Helen Titley, Met Office [ONLINE]

When forecasting tropical cyclone hazards such as flooding due to heavy rainfall, it is important to exploit the information on forecast uncertainty that is provided by ensemble prediction systems. There have, however, been very few studies investigating the ability of global ensemble forecast models to provide useful forecasts of the rainfall associated with landfalling TCs.

Traditional grid-to-grid precipitation verification methods offer little diagnostic reasoning on the performance of the forecast models that could be fed back into the model development process. Feature-based verification methods identify and isolate precipitation features in forecast and observation fields, and then verify attributes of these object pairs such as their intensity, area, shape, structure, and centroid location. These provide more useful information on model performance that can guide model developers on where to focus resource to improve the forecasts.

This study explores for the first time the use of three object-based methods to verify ensemble forecasts of tropical cyclone rainfall: i) the SAL (Structure, Amplitude and Location) method (Wernli et al. 2008; 2009); ii) the Method for Object-Based Diagnostic Evaluation (MODE) (Davis et al.

2006; 2009); and iii) the Contiguous Rain Area (CRA) method (Ebert and McBride, 2000; Ebert and Gallus, 2009). Three ensembles are included in the study: the ECMWF Ensemble Prediction System (EC ENS), the Met Office global ensemble (MOGREPS-G), and the NCMRWF Global Ensemble Prediction System (NEPS-G). Rainfall forecasts from these three ensembles are verified with the three object-based verification methods for four recent landfalling cyclones in India: Cyclones Nivar, Burevi, Tauktae and Gulab. The verification results are compared across the methods, cases, and ensembles, illustrating how object-based methods can help to identify the strengths and weaknesses of global ensemble forecast models in forecasting tropical cyclone rainfall.

Verification of super ensemble products based on high resolution perturbed forecasts by two global ensemble prediction systems	Ashu Mamgain, NCMRWF

This study aims to quantify the skill of “super ensemble forecast” products generated using two high resolution global Ensemble Prediction Systems (EPSs). The super ensembles are generated using the perturbed forecasts by two global EPS being run at NCMRWF and IMD, India. The EPS system, NCMRWF global EPS named as NEPS-G, is based on UK Met Office MOGREPS system and the other EPS, being run at IMD is based on GEFS of National Centers for Environmental Prediction (NCEP), USA. Both the operational EPS are of ~12 km horizontal resolution and both perturbed forecasts (NCMRWF and IMD) are available at TIGGE portal (ECMWF).
Statistics generated using seven days perturbed forecasts of NEPS-G’s 22 members and GEFS’s 20 members. NEPS-G ensemble forecast is the combination of 11-member perturbed forecast based on 00UTC and lagged 11-member perturbed forecast based on 12 UTC. The 20 member GEFS perturbed forecasts are based on 00 UTC initial conditions. The 42-member super ensembles using NEPS-G and GEFS areprepared during July and August of 2019. Performance of the super ensembles are assessed with respect to the individual EPS forecasts. The variables such as Zonal Wind at 850 hPa, Geo-potential at 500 hPa, Temperature at 850 hPa and Precipitation are used in the preparation of verification matric, for the Northern Hemisphere and RSMC (India) regions. The metrics used for verification are ensemble-spread, ensemble root-mean-square error, brier score, relative operating characteristics-based area skill score, reliability, rank histogram, ranked probability score, continuous ranked probability score etc. Significant improvements are noticed, especially in some of the verification scores, in the super ensemble. Details will be discussed in the workshop.

PARALLEL SESSION 10: Forecasting extreme weather events

Thursday 2nd March 2023

Case study on cold wave conditions over northwest India during 2022	Sri SP Singh	IMD

Qualitatively, cold wave is a condition of air temperature which becomes fatal to the human body when exposed. Quantitatively, it is defined based on the temperature thresholds over a region in terms of actual temperature or its departure from normal (based on 30 year average of temperature). India Meteorological Department (IMD) Criteria for declaration of Cold Wave conditions is when minimum temperature of a station <10°C for plains and <0°C for hilly regions with minimum temperature departure should be lie in range between -4.5°C to -6.4°C from normal temperature and based on actual minimum temperature (for Plains only) Cold wave can be declare when minimum temperature is <4°C for at least two station any sub-division of country for conjugative two days.
Major Factors for Cold Wave occurrence over India: Build up of a ridge (an extended area of relatively high atmospheric pressure) in the jet stream over northwest Asia. The formation of surface high-pressure over north & central India and movement of cold air masses in response to steering by upper-level winds. A triggering mechanism like strong westerly waves approaching plans of northwest India to enhance winds for transport cold air southeastward with the extensive snow covers over the Himalayas.
IMD issued regular colour coded impact based warnings for 36 Meteorological sub-divisions and approximate 739 districts issued 4 times a day by National Weather Forecasting Centre (NWFC) from IMD HQ New Delhi and twice a day by Regional Meteorological Centre/ Meteorological Centre (RMC/MC) for upto 5 days. Colour code warning has four types of colour e.g. Green colour shows minimal impact (no severe weather expected), yellow colour shows minor impact (be aware), orange colour shows significant impact (be prepared) while red colour shows severe impact level (take action).
During the winter season of 2022 the forecast by the IMD of Cold Wave over North West India well predicted that with sufficient lead period it helped disaster management and the general public to minimize loss of life and properties. Forecast skills also were very high with Probability of detection (POD) of Cold Wave is more than 90% and False alarm rate (FAR) is less than 5%.

Identification of Heat waves zones over India	G. Ch. Satyanarayana	Koneru Lakshmaiah Education Foundation

Heat waves are studied to understand their regional vulnerability, causation over the Indian subcontinent in the context of the current global warming scenario. An updated, high resolution gridded surface airtemperature data sourced from the India Meteorological Department (IMD) for the recent 72-year period (1951-2021) is used to ascertain the regions of maximum temperatures and heat wave vulnerability during the hottest month of April and May. Results reveal three distinct regions of maximum temperatures, over West Rajasthan in Northwest, North Madhya Pradesh and Southwest Uttar Pradesh in North-central, and East Maharashtra in South-central parts of India based on both the magnitude and frequency days of maximum temperatures. Contrastingly, three localised regions of heat wave vulnerability were identified in the north, northeast and southeast parts of India incontrovertibly different from the three maximum temperature zones. Soil temperature data confirm the regions of the maximum temperatures and the heat waves indicating the accentuation due to local radiative heating. The causation of heat waves was identified as the advection of heat by anomalous southwest, west and northwest wind flow from the three maximum temperature zones. Heat waves over southeast India, manifesting since 1970 denote the impact of global warming in recent decades. Climate model simulations of the current climate conform with the observed maximum temperature zones indicating the role of radiative heating. This study discerns the regions of maximum temperatures and heat wave vulnerability and identifies the causation to be triggered by wind flow from the maximum temperature zones under favourable atmospheric circulations. Results from this study would find wide application not only in the prediction, but also in the risk and vulnerability assessment.

Spatial verification of heat waves over Indian region	Harvir Singh	NCMRWF

For the spatial verification of heatwaves first time we have used the state-of-art technique object-based (MODE) verification. For the purpose of mitigation and reduction of damages due to heatwaves timely and accurate forecasts are required. In order to check the accuracy and to generate more confidence in using these forecasts, a thorough assessment of the forecasts is much need. Many traditional verification methods are commonly used to assess the performance of numerical weather prediction (NWP) models in predicting extreme weather like heatwaves. These methods have a limited utility as they are dependent only on a match at a grid-to-grid level. Spatial verification techniques, such as features or object-based approaches, can illustrate the model performance in a significant way by differentiating between forecast and observed spatial features and comparing their scale, shape, size, orientation, coverage area, displacement and intensity. This study aims to investigate the spatial characteristics of heatwaves over Indian region. The study utilizes IMD's observational data and NCMRWF unified model (NCUM) numerical data analyzed the synoptic conditions and factors that contribute to the formation of heatwaves. The study period is chosen to be March to May 2022. This study showed that NCUM forecast objects had a possible perfect timing and propagation of Tmax $\geqslant 41^{\circ}$ C objects when compared to the observations. Based on the total interest, which was the integrated quantitative measure of all the attributes and its values were the in the range of 90-97% up to 120 hr lead times. From the above analysis it can be summarises that NCUM mode able to forecasts the heatwaves structure, shape and size well in advance up to 120 hr lead times

Multi-model based Quantitative Precipitation Forecast for River sub-basin-wise during the monsoon season of 2022	Amit Bhardwaj	IMD

The summer monsoon rainfall is the major water source for most parts of India. The rainfall during JJAS period is the main source of flow discharge in most of the rivers. The monsoon season is also witnessed heavy rainfall over different river basins leading to major flood over different parts of India. The Multi-Model Ensemble (MME) based Quantitative Precipitation Forecast (QPF) using NWP global and regional models operationally prepared at IMD can provide useful guidance in flood early warning. Thus, in the present study, an attempt has been made to evaluate the performance of MME based QPF over 153 river sub-basins of India under 15 Flood Meteorological Offices (FMO) of IMD during the monsoon season of 2022 from June to September.

Satellite-based study on the extremely heavy rainfall episodes of northeast India during 2022	Shibin Balakrishnan	IMD

Studies using climate models demonstrate that as greenhouse gas concentrations rise, the earth's surface temperature rises, potentially increasing the intensity and frequency of extreme precipitation events. Flooding brought on by extremely heavy rainfall events has significantly negatively influenced human society regarding property loss and fatalities. Although extremely heavy rainfall spells can occur anywhere, some regions are more susceptible or prone than others owing to the influence of orography and flood zones. Airflow can impact mountain slopes, causing upslope flow, prolonged climb, and the production of precipitation over extended periods. This study investigated the extremely heavy rainfall spells in northeast India in 2022. Many meteorological sub-divisions of northeast India experienced extreme flooding along with regions of Bangladesh. The satellite-based rainfall is compared with the observational rain data to envisage the spatial and temporal displacement of the rainfall over the area. The current paper also examines the characteristics of extremely heavy rainfall in northeast India. The synoptic analyses are also carried out during the rainfall episodes to study the background process involved in flood situations over the regions.

Impact of different meteorological parameters on Heat Waves over India	Akhil Srivastava	IMD [online]

Heat Waves (HW) are one among major extreme weather events faced by humanity in 21st century owing to climate change, global warming and anthropogenic alterations of the environment. India being a highly populous country is at risk of greater impacts from these high temperature events. The March 2022 average maximum temperatures were highest in last 122 years (1901-2022) and that of April 2022 were the third highest in last 122 years. There have been various studies to document the causes and occurrences of HW events. However, the HW doesn't fails to surprise the weather and climate enthusiasts with its novel characteristics and new extremes of its spatial and temporal extents year after year. The Indian hot weather season of 2022 was no exception with starting two months (March-April) presenting the challenges of increased intensity and duration of heat wave impacting majorly northwest and central India. The March and April months of 2022 saw major HW events particularly during 11th -21st March 2022, 26th – 31st March 2022 and 25th – 30th April 2022. In this study a comparison has been made between the characteristics of the current observed HW events with climatologically recorded HW events along with the causes, factors and impacts associated to this year events.

Study of the Rapid Intensification and Rapid Weakening of Tropical Cyclone ASANI (May 2022) over the Bay of Bengal using NCUM-R modelling system	Shiva Ji Singh Patel	NCMRWF

The present study examines the predictive capability of the National Centre for Medium Range Weather Forecasting Unified Regional Model (NCUM-R, 4 km horizontal resolution) for pre- and post-genesis of tropical cyclones over Bay of Bengal. The main aim of this study is to check the forecast skill of the NCUM-R model for extreme weather events, and whether the NCUM-R model is able to predict or capture any signal 2-3 days advanced to predict the intensity and track of a Tropical cyclone (TC). For the study, we have chosen the Severe Cyclonic Storm (SCS) "Asani" which formed over the Bay of Bengal (BoB) between 7th to 12th May 2022. On the 8th of May in the morning, the storm became a tropical cyclone with central pressure dropped by 7 hPa from normal and surface wind speed was 40 knots. To examine the pre-genesis and development of the storm, we have taken the model analyses and forecasts 2 days prior (IC-06May2022). The cyclonic storm (CS) became a severe cyclonic storm (SCS) at 12UTC on 09 May 2022, to examine the evolutions of the storm at the mature stage we have taken model analyses and forecasts on 08 May 2022. In the initial stage, the moisture coming from the equator side contributed to the development of the TC. The wind blowing along the equator is moist and humid, and it releases an adequate amount of latent heat in the vicinity of the storm. Another criterion is that relative vorticity (RV) should be in the proper range; at the time of the storm, the RV was 3.3×10-5 s-1. The NCUM-R model successfully predicted these processes during the pre-genesis period. The role of other various thermodynamics and dynamics variables; intensity; track and error at various stages of TC are also examined. The model well captured the thermodynamics variables like genesis potential parameters (GPP), potential vorticity (PV), and relative humidity. These parameters clearly demonstrated TC Asani's fast intensification and weakening. The pattern and intensity from NCUM-R simulations output are well matched with IMD observation and ERA-5 reanalysis. Based on the study, the NCUM-R model can effectively forecast the storm's intensity, movement, and structure prior to and after its origin.

Impact Assessment of Tropical Cyclone on the Landfall Region: A case study of FANI Cyclone, Odisha, India using NEPS Model	Vivek. G	Azim Premji University

Globally, there is a paradigm shift in studying the impacts of coastal hazards and studies are being oriented towards quantifying the effects to minimize damage to life and property. In India, the most common natural disaster the tropical cyclone (TC), can cause severe impacts, including damage to life, property, infrastructure and vegetation as it makes landfall accompanied by heavy precipitation and extreme wind speed of more than 100 km/hr. The damage caused by the TC depends on the size, intensity, track, speed of the cyclone and the socio-economic conditions of the coastal areas where landfall occurs. The extremely severe cyclone Fani which devastated the coastal regions of Puri in Odisha was one of the strongest tropical cyclones since the 1999 Odisha cyclone. Information about the possible impact of the cyclone before its landfall would greatly benefit mitigation operations. In this study, the impact of tropical cyclone Fani which made a landfall on 3rd May 2019 was analysed two days in advance using the predicted cyclone track from IMD along with weather model NCMRWF Ensemble Prediction System (NEPS) derived precipitation, wind speed and socio-economic data of coastal Odisha. Heavy rainfall and a wind speed of more than 200 mm/day and 185 km/hr, respectively was forecasted at the coast of Puri and its neighboring districts during cyclone landfall. The six coastal communities are forecasted namely, Puri, Khurda, Jagatsinghapur, Kendrapara, Jajapur and Cuttack, will be severely affected due to heavy rainfall and high wind speed caused by Fani cyclone. And around 1.3 million people were under moderate risk, 1.9 million people were under high risk, 1.6 million people were under very high risk, and 0.7 million people were under extremely high risk. Post cyclone field survey was carried out in these affected districts and during the survey we observed that kutcha houses, with temporary wall and roof, were severely affected due to high wind speed, which indicated that the strong winds inflicted significant damages to infrastructure and vegetation.

Comparison of the region of heavy rainfall for Cyclone AMPHAN, YAAS and JAWAD.	Sourish Bondyopadhyay	IMD

Synoptic Features Associated With Heavy Rainfall Events In Andhra Pradesh State During Monsoon Season 2022	Sunanda M	IMD

The study is to analyse the Heavy rainfall events over Andhra Pradesh state, which is a coastal state of Peninsular India, where both monsoon and post monsoon seasons contribute significant rain. Monsoon season 2022 was highlighted with Heavy rainfall events. In some districts of Andhra Pradesh state these events causing significant damage to public and private properties. An attempt has been made in this paper to identify the observational aspects, main synoptic system, physical process and thermodynamic features leading to such Heavy rainfall events during monsoon season. Analysis of the study indicates that Extreme Heavy rains are recorded over the state during Intensified low pressure systems Heavy to very heavy rainfall which is all time record rainfall reported on 9thSeptember 2022 at Visakhapatnam 21 cm was due to A low Pressure area is formed over North west and adjoining West central Bay of Bengal off south Odisha and north Andhrapradesh coasts and A trough runs from Konkan to Low pressure area and Shear zone lies in 15 degree N over south Peninsular India.

Efficacy of high-density rain gauge network in estimating extreme rainfall events over Mumbai during monsoon 2020-2022	Upal Saha	NCMRWF

The automatic rain gauge (ARG) and automatic weather station (AWS) are recognised as the ground-based in-situ observing systems for the source of direct measurements of instantaneous rainfall. Hence, deployment and proper maintenance of these AWS/ARGs are in high demand which would help the policy makers to cope with unforeseen situations caused by intense rainfall events. MESO-scale rain gauge NETwork (MESONET) consists of ~142 AWS/ARG stations deployed over the Mumbai metropolitan region (18.80N-19.350N, 72.80E-73.250E) by various agencies (IITM, MCGM, IMD and SAFAR). This study presents the results for the quality monitoring and verification of station rainfall observations from this high-density Mumbai-MESONET during the monsoon (June–September, JJAS) months of 2020-2022. During the southwest monsoon, Mumbai and surrounding region receives copious amount of rainfall and drains overflow causing local flooding. Hence, checking the quality and usability of these rainfall data is very important for controlling and managing the flood affected zones. There were 269 heavy rainfall (HR) events, 127 very heavy rainfall (VHR) events and 22 extremely heavy rainfall (EHR) events during JJAS: 2020-2022 over Mumbai making a totality of 428 rainfall extremes in the last 3 years. There were 83 collocated AWS/ARG stations (situating within 5 km from the centre of the locations of extreme rainfall events) out of 142 stations in the vicinity of the rainfall extreme locations. NCMRWF has indigenously developed a quality checking module based on the computed statistics between the actual observations and the collocated AWS/ARG stations reporting regular rainfall observations. Results indicate that most of the collocated AWS/ARGs have captured the peak intensity with higher accuracy. Thus, the quality-checked high-density Mumbai-MESONET rainfall observations from the good quality regularly reporting stations can improve hydro-meteorological monitoring and this information will be very crucial for all the stake holders.

PLENARY 4: Forecasting extreme weather events

Tuesday 28th February 2023

Probabilistic Prediction of Active and Feeble Western Disturbances: Medium to Extended Range Leadtime of Multi Model Perspective	Arulalan T, IMD

Western disturbances (WDs) are formally defined by the India Meteorological Department as "cyclonic circulation/trough in the mid, lower tropospheric levels or as a low pressure area on the surface, which occurs in middle latitude westerlies and originates over the Mediterranean Sea, Caspian Sea and Black Sea and moves eastwards across north India". WDs are, at the most fundamental level, synoptic-scale vertical perturbations embedded in the subtropical westerly jet stream. They are often associated with extreme rainfall events in the Karakoram and Hindu Kush regions of Pakistan and north India, and have been the subject of a number of modelling case studies. The recent study Hunt et al., (2017) defined the algorithm to track WDs and found 3090 tracks using ERA-I reanalysis (1979-2016), elaborated the WD tracks by in terms of its associated precipitations (normal to heavy). In the current study, we implemented Hunt et al., 2017 algorithm on using NCMRWF, IMD operational forecasting institutes operational global models (NCUM, IMDGFS) analysis (near real time 4Dvar data assimilation) and global ensemble prediction system models (NEPS, IMDGEFS) with 21 members forecasts, upto 10 days lead-time and global models coupled with ocean for extended range prediction (NCUM-ERP and IMDGEFS-ERF) with 16 members ensemble forecasts upto 32 days lead-time, to predict the WDs tracks and its associated precipitation in a few days/weeks (medium-range) to month ahead (extended-range). We introduce a methodology to categorize the predicted WD as active or feeble by using these NWP operational global multi model ensembles, we identify the probability of occurrences of active/feeble WDs in one to four weeks lead-time, which will become an important key in planning and managing extreme weather events (heavy rainfall, drought) by various stockholders including operational forecasters during winter and transits from winter to summer seasons, also sometimes in monsoon season as well.

Evaluating the Heavy Rainfall Events of 2022 in NCUM-G and UKMO	Raghavendra Ashrit, NCMRWF

As per the India Meteorological Department 24 hour accumulated rainfall amount in the range of 64.5- 115.5 (115.6-204.4) mm/day is termed 'Heavy Rain' (Very Heavy Rain). During 2022 there were several events of Heavy Rains (HR), Very Heavy Rains (VHR) and Extremely Heavy Rain (>204mm/day; EHR). The study provides verification and intercomparison of NCUM and UKMO global models over India during 2022 and assesses the performance in comparison to recent past. Besides using the standard traditional verification metrics, the study uses spatial verification approaches involving CRA, MODE and FSS.

Medium and extended range forecast of monsoon over India: Prospects of its application in different sectors	D R Pattanaik, IMD

For a vast agro-economic country like India, the forecast of southwest monsoon rainfall on short to medium range (5 days) to the extended-range time scale up to about 3 to 4 weeks (prediction of the active-break cycle of monsoon) is vital for issuing reliable advisories to the farming communities of the country. As Agriculture production is directly influenced by monsoon performance over the rain-fed portion of India, the reliable forecast of monsoon in medium to extended range forecast can be very beneficial to the farming communities of the country.
Recently, India Meteorological Department (IMD) has augmented its NWP modelling capability and is now able to generate forecasts at very high resolutions; 12 km using Global Forecast System (GFS) & Global Ensemble Forecast System (GEFS) models and about 38 km using ocean-atmosphere coupled Climate Forecast System (CFS) model. These continuous efforts by MoES have enabled IMD to provide forecasts at the district/block level at short to medium-range time scales and met-subdivision/district at extended-range time scales.
In addition to the forecast products from GFS and GEFS models at 12 km resolution in the medium range time scale (Day 1 to Day 5 forecasts), IMD is also preparing Multi-Model Ensemble (MME) forecasts at the district level by using the outputs from six global models viz., the Unified Model from NCMRWF, GFS model from NCEP and Global Spectral Model (GSM) from JMA and ECMWF. Based on the evaluation of district-level MME forecast for the 2021 and 2022 monsoon seasons it is found that MME has the potential of predicting weather events in the medium range. Like in the medium range, IMD has also implemented CFSv2-based Extended Range Forecasts (ERFs) for application in Agriculture, which provides a skillful forecast for 2 to 3 weeks at the met-subdivision/district level. The present results show the medium and extended range forecast shows encouraging signals for applications in the Agricultural sectors.
In addition to the application of medium and extended-range forecast in the Agricultural sector, the present analysis indicates that the prediction of the active phase of monsoon in the extended-range time scale and the prediction of heavy rainfall events at district and river basins scale in the medium-range time-scale has wide application in the hydrological sector and application in the disaster management.

Improved TC Science for better decision making	Monica Sharma, IMD [online]

India Meteorological Department acts as Regional Specialised Meteorological Centre, New Delhi to provide tropical cyclone advisories and associated adverse weather information to 13 WMO/ESCAP panel member countries in the North Indian Ocean region. IMD also handholds member countries to carryout various technological improvements and provide support to improve the competency of forecasters in the region through trainings, sharing of best examples, reports and data on tropical cyclones. During recent years, there has been a move by various National Meteorological and Hydrological Services (NMHSs) to implement impact-based forecasts (IBF) and risk-based warnings (RBW) in their respective area of concern using probabilistic model guidance. The IBFs and RBWs taken into consideration the uncertainties in the individual hazards and provide the disaster managers the information about the actual impact on users. The hazard guidance for better decision-making by the forecasters requires probabilistic data for all hazards at varying spatial and temporal scales. The hazard forecast for mitigating the disaster requires impact based forecasts as per user defined thresholds, effective communication and dissemination. However, the IBF has not been implemented uniformly across all the countries in the region because of lack of tools, lack of socio economic data and lack of methodology for development of these forecasts. Thus, a review of developments in the field of IBF and RBW at IMD has been carried out to share the knowledge and best practices with member countries in the region. It would enable the NMHSs to implement IBF in their country and thus reduce damage to life and property due to TCs in the region.

Background reading

The latest meeting agenda and other workshop details can be accessed via the NCMRWF meeting webpages.

A copy of the WCSSP India Annual Science Highlights Report 2022-2023 providing a UK WP-lead summary of project progress is accessible via the project sharepoint pages.

Further project background, archive of project deliverables, meeting materials and Collaboration Space are also accessible to registered users via the WCSSP Sharepoint. For more information on accessing these pages, please contact the WCSSP Programme Office WCSSPProgrammeOffice@metoffice.gov.uk